# Developing a comprehensive framework for property valuation using 3D and remote sensing techniques in China

JINGXUAN ZHANG
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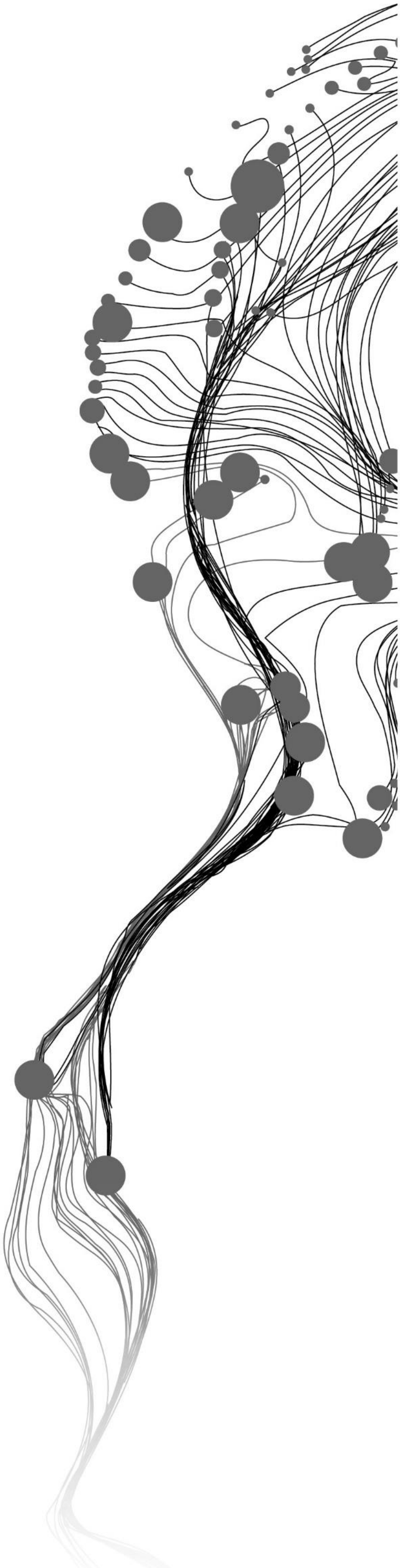

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Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Urban Planning and Management

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# ABSTRACT

Residential properties as an immovable commodity, connects the human activities to a certain location, playing a vital role in our lives with a bundle of complicated characteristics. Traditional valuation approach focusing on the physical and locational factors of the property, which are the 2D dimensions of housing characteristics. While the users or so-called potential property buyers also concerns environmental aspects and amenities like clean air and beautiful views. These factors related with the height of the property (3D dimension), influencing the price yet few researches had done to analyse the relationship between these factors and the price.

This study proposed a framework for property valuation based on user requirements, focusing on both 2D and 3D dimensions of the properties. Requirements of users were acquired through questionnaire and quantified via remote sensing and 3D techniques including image classification, building information modelling (BIM), viewshed analysis and sun volume analysis. Quantified 2D and 3D indicators were imported to two regression models to analyse the contribution of integrating 3D factors in modelling property prices. The framework is then constructed base on the result of regression.

Comparing the result of two regression model, the study proved the significant increase in model fit using both 2D and 3D factors to model property prices, showing the necessity of integrating 3D information. Influential factors for property prices include distance to high school/metro station/tourist attractions/business centre, sun duration, view of buildings/vegetation/water. The formula for predicting property prices was summarized from the regression result. The validation and evaluation with user feedback show good performance of the framework and the applicability from practical perspective.

From the perspective of users, the proposed framework is able to fulfil needs for valuating a property with little requirements on user input, comparing characteristics of several properties with explicit scores, and contributing to the decision-making process for property purchasing. It provides the information that users want to know. With further development, it can help users search all properties with desired quality or requirements on a specific indicator. From the perspective of government, the proposed methodology and framework is simple and explicit. With the extensive data and better computation power acquired by the government, the framework could also serve as the basis for large-scale property valuation and taxation purposes.

**Keywords:** Property valuation, BIM, remote sensing, framework, CityEngine

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# 1. INTRODUCTION

## 1.1. Background and justification

The value of the properties is influenced by locational, physical, legal and economic factors (Sayce, Cooper, Smith, & Venmore-Rowland, 2006; P. J. Wyatt, 1997). According to Wyatt (2013), locational factors include accessibility, proximity to services or infrastructures, etc. The physical factors refer to the characteristics of the property, including size, age and condition. Legal factors often refer to the restrictions, rights and responsibilities of the owners as well as the terms and covenants of the properties. Economic factors are more related to market forces. Another important characteristic of the value of the property is that it is strongly influenced by demand and supply. People's preference for residence is embodied in a preferred location, a range of affordable price or requirements on a certain design of the house, etc. These requirements from buyers will shape the market in terms the types of housing that are available in the market. Thus, personal preference or user requirements have an impact on property value.
Valuation of properties is done for several purposes, including taxation, sales and acquisition, insurance, and eminent domain, as well as influencing policies to support living standards and satisfaction of people. Property valuation refers to the process of estimating the amount for which a property will be exchanged on a particular date, given certain conditions, for a particular purpose (RICS, 2017; P. Wyatt, 2013). This is a complex process, which is affected by multiple forces including data and transparency of the market, intricate heterogeneous nature of property itself, diverse purposes and stakeholders involved, etc. (RICS, 2017; Sayce et al., 2006). It is also strongly influenced by the educational background and experience of the person who conducts the valuation, as well as the global trend on economic development and investment interests (Ndungu, Makathimo, & Kaaria, 2002; Źróbek & Grzesik, 2013). Multiple studies and models had been developed under different local contexts to quantify the influential factors and analyze the relationships between factors and value (Blanco & Flindell, 2011; Fik, Ling, & Mulligan, 2003; B. Huang, Wu, & Barry, 2010; Yang, Yajun, Yuqing, Xueming, & Quansheng, 2017; Yu, Wei, & Wu, 2007).
Among all the indicators affecting the property value, locational factors are often the significant ones when holding the physical characteristics of the property constant. An example is the effect of the proximity to the CBD, schools or industries to property values (Fik et al., 2003; P. Wyatt, 1996). Acquiring spatial information is quick and easy with the help of remote sensing techniques and spatial analysis (Jain, 2008a; Patino & Duque, 2013). It provides up-to-date images and offers an efficient way to extract data and conduct analysis on accessibility, proximity to a job or educational resources, open space, amenities and neighborhood's development (Dąbrowski & Latos, 2015). These data can be used for analysis on locational and physical factors mentioned above. However, when buying a residence, people also show emphasis on other factors related to the height of the property, which was not reflected in current valuation standards nor attracted attention from researchers. These 3D indicators of the property like the diversity of urban functions (commercial, residential, etc.) in the vertical dimension, overlapping ownership boundaries in high-rise buildings, and view from the property cannot be seen in 2D images. Hence, 3D indicators would be beneficial to be introduced in the process of property valuation, which is the aim of this study. Building information modelling (BIM) as a newly developed approach, can be adopted to integrate 2D and 3D indicators for property valuation. It models the 3D physical and functional characteristics of building objects and serve as an data-sharing tool in support of management throughout the building life cycle (National Institute of Building Sciences, 2018). It is a comprehensive and intelligent 3D approach for different stakeholders involved in designing, interacting, collaborating and managing buildings (Eastman, 2011). BIM provides abundant information on designing and construction

of the property, which is useful for both practical application and research (Olawumi & Chan, 2018; Röck, Hollberg, Habert, & Passer, 2018). In addition, Atazadeh, Kalantari, Rajabifard, Ho, and Ngo (2017) discussed using BIM on visualizing physical and legal ownership information, which would make a great contribution in managing properties. Using BIM to address problems in property valuation related to 3D indicators of the properties has not been explored. In light of the above, BIM can be integrated to enrich the valuation system. Furthermore, the potential of BIM and remote sensing (RS) integration for property valuation will be explored in this study.

This study aims at formulating a comprehensive framework including 2D and 3D indicators for property valuation. All the indicators will be identified after a thorough literature review, review of policies and legal documents and a fieldwork survey. Spatial information and a 3D model of the study area will be created through RS data and modelling techniques, as the basis for a more detailed analysis and the construction of the framework.

## 1.2. Research problem

### 1.2.1. Practical aspect

Chinese cities expanded rapidly during past decades with the enormous demand on housing and supporting facilities. This need is driven by population growth, economic development, policies, and the agglomeration of resources in urban areas. People flow into cities to have better access to opportunities and better living environments. One important step of settling down in a city regarding the Chinese culture is to own a house, which accelerates the development of the real estate market. The field of property valuation blossomed with the absorption of international knowledge and standards, as well as the massive number of valuers and agencies. Yet the government did not have a comprehensive regulation or legal force targeting this field, which resulted in a chaotic market (T. Chen, 2018; Guangyuan, 2017; Liu, 2013). With the regulatory framework issued by the Ministry of Housing and Urban-Rural Development of the People's Republic of China in 2011, the procedures of property valuation in China is restrained and able to fulfil various needs. Regarding the unique land utilization system in China, the valuation process and influential factors are different from other countries, which attracts researchers to analyse this (Y. Huang & Clark, 2002; Xu & Li, 2014).

Currently, valuation is mainly conducted by banks and qualified valuation agencies, following the standards focusing on the location, purpose, land, recent market prices and their direction, etc. (Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2011). However, people are not satisfied with the results they provide (Gao & Li, 2018). This comes from the gap between the valuation result and the transaction price, also because the process is costly and time-consuming during investigation. Examples were reported in China business news and Beijing daily (Liu, 2013; Luo, 2015), pointing out problems like differences on service charge, lacking a systematic approach and neglecting attitude of the valuer during an inspection. Most people would take simply check the price of another house with similar conditions, compare it with their property, and roughly estimate the price based on their fuzzy perception. This reveals the fact that the services provided by the current valuation system cannot satisfy the needs of people. Another drawback of the current valuation standard is that it does not reflect the actual factors that a user would consider when looking for a residence. People have "invisible" requirements such as daylighting, view of the house and noise level (Aswin Rahadi, Wiryono, Koesrindartoto, Indra, & Syamwil, 2012; Saptutyningsih, 2013). These factors are related to the height of the property, being the selling points proposed by real estate companies, which can be easily found in any available on-sale housing website. Since real estate companies use these selling points to attract customers, the transaction price of the property is also influenced when the height of property changes. In this case, the valuation process should take this aspect into account, which is actually not done in practice.

#### 1.2.2. Research gap

As the two practical problems mentioned above shows, the gap falls between the user requirements and services provided by the market, and lack of knowledge on how 3D attributes of the property influencing its value. Researchers in the field of remote sensing have had fruitful achievements on valuation of land and property (Canaz, Aliefendioğlu, & Tanrıvermiş, 2017; Jain, 2008b). For example, hedonic pricing model and geographically weighted regression model (GWR) are widely applied approaches estimating the value of properties based on its spatial characteristics. Fik (2003) explores how the interactive locational variables influence property value using hedonic pricing model. Yu (2007) added remote sensing information to a hedonic pricing model with conventional attributes and investigated how this could help to reduce the problem on spatial autocorrelation. Blanco and Flindell (2011) applied hedonic pricing model and explored the relationship between housing price and noise level. These authors stressed the lack of data on whether people would consider noise as an influencing factor or not, they proposed future study. Yang et al.(2017) found a significant influence of accessibility on housing price using GWR for the case Dalian, China. Where B. Huang et al. (2010) integrated temporal factors with GWR, revealed substantial contribute on modelling housing prices.

The above studies tried to better model property value from many aspects, yet they did not add 3D attributes in their research, resulting in a lack of knowledge on how height influences housing price. With the development of 3D modelling, more researchers turned their attention into this field. Xu and Li (2014) applied 3D visualization to show the spatial distribution of buildings with different housing price. Rafiee, Dias, Fruijtier and Scholten (2014) combined BIM model with spatial information and conduct view analysis, which can be further used to support the work of planners and architects. To the best of author's knowledge, little research had done to have a systematic way of combining both 2D and 3D information to explore if this could contribute to better model housing price. Thus, this is a novel research focus.

Since the property valuation process involves many aspects and complexities, the scope of the study will only focus on the residential property valuation in China. Main objectives of this study are: understanding the need of the users, quantifying the requirements into measurable indicators and analyzing its relationship with the price of the property. Finally, the framework aims at providing an easy-to-follow procedure for residential property valuation for people in need of assessing the value of their property.

### 1.3. Research objectives

#### 1.3.1. General objective

To develop a comprehensive framework integrating 2D and 3D data based on remote sensing techniques in support of property valuation in China.

#### 1.3.2. Sub-objectives

Sub-objective 1: To identify factors influencing property values through review of literature and other related regulations.

Sub-objective 2: To develop a framework for property valuation using 3D and BIM based on users' requirements.

Sub-objective 3: To evaluate the performance and limitations of the framework.

### 1.4. Research questions

1. Sub-objective 1: To identify factors influencing property values through review of literature and other related regulations.
    - What are the influential factors, methods, and models identified by researchers in the field of remote sensing and BIM to support property valuation?
    - What are the currently-used indicators for residential property valuation in China?

2. Sub-objective 2: To develop a framework for property valuation using 3D and BIM based on users' requirements.
    - What are the users' requirements for factors influencing property values and their importance?
    - What are the methods used in RS and BIM to quantify those indicators?
    - What are the relationships between factors and the property value?
3. Sub-objective 3: To evaluate the performance and limitations of the framework.
    - To what extent does this framework satisfy the needs of users?
    - What are the strengths and weaknesses of this framework?

## 1.5. Conceptual framework

The key concepts and their relationships are shown in Figure 1. As illustrated in section 1.1, the value of the property is influenced by locational, physical, legal and economical indicators, which in the empirical studies does not include building height information. Current valuation standards focus on this 2D indicators. Yet according to people's perception, they also consider factors that are related with height (3D). And the importance level from users' perspective is not the same as in the current standards. This study aims at combining 2D and 3D indicators, based on user requirements, to develop a 3D property valuation framework.

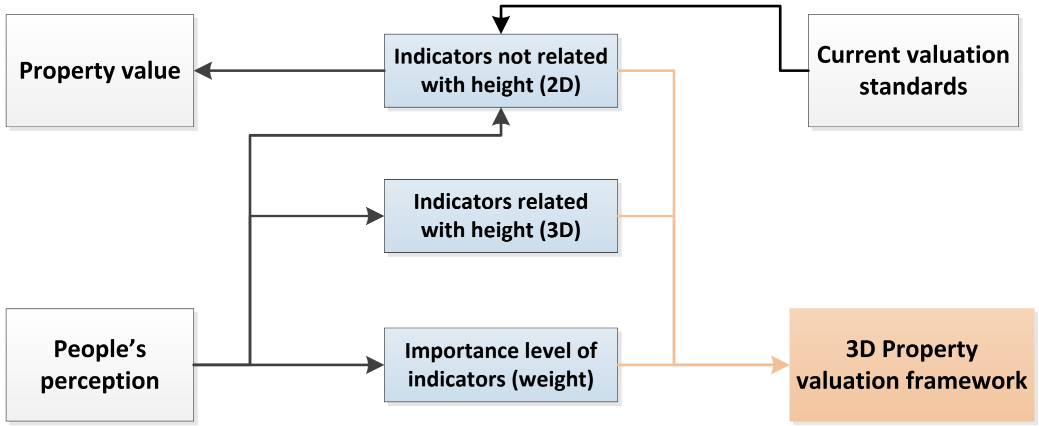


Figure 1 Conceptual framework

## 1.6. Anticipated result

The anticipated result of this study is listed below.

- Indicator list No.1: influential indicators on residential property value retrieved from the literature review and interview with experts.
- Indicator list No.2: indicators with its weights derived from questionnaires, which will be compared with list No.1. This list contains 2D and 3D indicators, which are the inputs for regression model.
- BIM model of the study area.
- Regression model using 2D indicators: Indicators and its statistical results.
- Regression model using both 2D and 3D indicators: Indicators and its statistical results.
- Reflection and discussion through comparison of the above results.
- Developed framework

### 1.7. Thesis structure

Chapters of the thesis will be structured as below.

Chapter 1: Introduction; Chapter 2: Literature review; Chapter 3: Methodology; Chapter 4: Result and discussion; Chapter 5: Conclusion and recommendations.

# 2. LITERATURE REVIEW

## 2.1. Property valuation in practice

During the past decades, rapid urbanization took place around the world, triggering huge expansion and development of cities. Real estate as the product connecting human needs and economic production drew the attention of everyone, including the government, investors and citizens. According to Wyatt (2013), real estate is defined as "physical entity whereas real property is the legal interest in real estate which entitles its owner to various rights". He specified that the target of valuation is the physical entity together with the legal rights which are strongly connected with the rights of exchange, operating activities within the defined parcel and period of ownership. One additional concept needs clarification is the difference between price and value. Price is a numeric term for the money exchanged between investors, whereas value is the objective estimation of a commodity and varies between the investors (Olajide, Lizam, & Olajide, 2016; Sayce, 2006). In this study, price is discussed and analysed.

The real estate market in China composited a vital part of the government fiscal revenue, which was a result of tax reform and the land-granting system (R. Zhang, Du, Geng, Liu, & Huang, 2015). Therefore, it is of great importance for the government to know the price of the property for taxation purposes. Defined by the Ministry of Housing and Urban-Rural Development of the People's Republic of China (2015), four main types of approaches are adopted in China.

*Sales comparison approach* assumes that the price of the valued property is similar to a recently transacted property, which possesses identical or similar assets. Modulations can be done according to the conditions of the market, difference on locational factors and the distinctions on rights. The valuer needs to carefully define a reasonable time scope as "recently". When applying modifications to the price according to the assets of the properties, factors including area, structure of the building, equipped facilities, decoration condition, layout, function of the building, outside appearance and date of construction. The modified price should not exceed 20-30% of the reference price. Though this method is widely used in valuation activities, it is bounded by the experience of the valuer and data on transaction records (Adetiloye & Eke, 2014).

*Income capitalization approach* values the property based on its potential benefit/income and the duration of return or ownership. The appropriate duration of return is usually 5-10 years. This method uncapitalizes the direct comparison between properties into initial market value and rental value (Pagourtzi, Assimakopoulos, Hatzichristos, & French, 2003). Thus, it is still a comparative approach based on previous sales examples. All the overheads should also be taken into consideration when estimating the annual rental income, including maintenance and renovation of the building, etc. But this method is not appropriate when the property does not produce revenue, like schools, parks or churches (Z. Chen et al., 2017).

When the property is too special to find similar sales as reference, or no rental has been produced, *the cost approach* can be applied. It assumes the value is equal to the market value of land and the reconstruction of the building, together with the cost generated during the simulated process of construction, like cost for management and investment interest, cost for marketing, etc. It is also known as the contractor's approach. Yet the limitation comes when the market value of the property is not only determined by these costs on land or buildings, but also the type of use or activities happens in the building. Examples are the property price of business centre, which contains small proportion of cost on building, and major cost on gross yield and tax (Guo, Xu, & Bi, 2014).

*The hypothetical development approach* estimates an unused or undeveloped piece of land based on different scenarios. The purpose of such method is to estimate the value based on its highest and best use after analysing different schemes for development (The Hong Kong Institute of Surveyors, 2016). It is helpful for decision making process between development alternatives and project assessment, which is often used in redevelopment and compulsory land acquisition by the government (Mcdermott, Sylla, Antonio, & Wanyonyi, 2018).

Despite the traditional approaches mentioned above, there are other methods that gained acceptance with the development of valuation market, like the automated valuation models (AVMs), also known as Computer Assisted Mass-Appraisal (CAMAs) (Glumac & Des Rosiers, 2018). International Association of Assessing Officers (IAAO) is one of the biggest organizations in the field of real estate appraisal, involving in setting the internationally accepted norms. They referred AVMs as a statistical model that evaluates the value of properties based on its characteristics and geographic data. A set of up-to-date and reliable records about sales and cost data is required for statistical tests (International Association of Assessing Officers, 2017). Various statistical models can be applied under the context of AVMs including hedonic pricing model, multiple regression or clustering analysis (Giuffrida, Ferluga, & Valenti, 2014; Helbich, Jochem, Mücke, & Höfle, 2013; Liman, Sipan, Olatunji, & Afrane, 2015; Oberman -Clive et al., 2013).

The following sections of literature review detailed the approaches adopted by researchers and applications of different techniques in the field of valuation.

## 2.2. Property valuation in research

### 2.2.1. Hedonic pricing model

The price of residential real estate is heavily influenced by the price of land that the property locates, due to its intrinsic connection between human needs and location (Chin & Chau, 2003; Rosen, 1974; Sirmans, Macpherson, & Zietz, 2005). Extensive models and researches were presented to investigate the pattern and influential factors of land value. Traditional land value models include bid-rent theory/trade-off model by Alonso (1964), concentric-zone model by Burgess (1925), sector model by Hoyt (1939) and the model of Mann (1965). These theories of urban land use and pattern reveals the locational distribution of different types of land use, which to some extent indicates the locational and neighbourhood characteristics that effect land value, and the corresponding value of the property that locates on the land (Pacione, 2005). Across these theories, the main factor influencing value is proximity to central business center (CBD). Through the evolution of theories, monocentric and circular layout of land use changed to polycentric and complicated form of distribution. Yet the common factors remain the same, which can be summarized into three dimensions: accessibility, quality of neighbourhoods and quality of environment. Accessibility includes proximity to CBD and sub-centers, which can be measured not only by physical distance, but also monetary value of time and cost required for the trip (Cervero, 2015). Quality of neighbourhoods refers to the socio-economic characteristics, like supporting facilities and amenities. Quality of environment for example can be fresh and clean air, since no one would want to live close to industrial sector.

Hedonic pricing model has been widely applied in property valuation market to estimate the value based on the attributes of the property as well as external factors (Abidoye & Chan, 2017). This model comprehends the property as a bundle of attributes that cannot be separately exchanged in the market. Based on this theory, how does each attribute contribute to the price of the property is analysed. Since it breaks down an integrated commodity into individual components, it is useful when focusing on attributes from specific dimensions (environmental, locational, economical, etc.) (Sirmans et al., 2005). The most criticized limitations of this approach found in empirical studies are spatial autocorrelation and misspecified statistical function form (Helbich et al., 2013; McMillen, 2010). The former emerges from a similar pattern of prices for nearby properties. It is obvious since nearby properties share the same quality of neighborhoods and environment. Additionally, proximate buildings tend to be developed in the same time period, resulting in similar structure, style and price (Ismail, 2006). The later problem refers to the assumption that all attributes share a linear relationship with property prices (McMillen, 2010; Rosen, 1974). To avoid these problems in this study, all factors were first plotted to see its relationship with price. Analysis on spatial autocorrelation in ArcGIS was also performed.

#### 2.2.2. Application of remote sensing and BIM techniques in property valuation

The value of the property is influenced by almost unlimited amount of factors that no research would be able to contain them all (Sirmans et al., 2005). It is not only restricted by the assorted conditions of different study areas, but also the limited number of samples to perform analysis. In addition, problems of multicollinearity and spatial autocorrelation occurring between indicators could bias the result (Ismail, 2006; McMillen, 2010). Thus, extensive researches had been done to analyse the influential factors of property prices while focusing on different dimensions.

Remote sensing data with diverse resolution and time scope are now widely available, served as a fundamental data source for researches on property valuation. For example, Franco & Macdonald (2018) explored the role of remote sensing in valuing the impact of urban greenness and amenities on property value using aerial images obtained from Intergraph Digital Mapping Camera with a resolution of 0.5m. They extracted the normalized difference vegetation index (NDVI) and tree canopy coverage using the support vector machine (SVM) algorithm. Their accurate classification result indicating remote sensing of ground objects can be integrated in the valuation process. Jain (2008b) acquired social-economic attributes from high-resolution imagery for the purpose of property taxation. From the Ikonos imagery, roof material, shape and structure of the buildings, age of construction was identified using object-based classification. Together with parameters proposed by the municipality, zoning of groups with different socio-economic status were extracted. The author showed the possibility of remote sensing techniques applied in information extraction for researches on social problem. Zhang et al. (2019) applied spatial interpolation for producing a DEM map visualizing urban housing prices. The three-dimensional visualization of housing prices combining with water-flooding method (using benchmark price as "flood") and section-cutting method, simulated and identified the price peak in the city. They further analysed the spatial morphology of prices along with key traffic lines using belt-floating method. Their study showed a different methodology and brought new insights for analysing urban housing prices.

With the development of 3D cadastre and building information modelling (BIM), more and more researchers started to examine the potential of 3D modelling in topics related with property management, taxation and valuation. Atazadeh and other researchers in their work (Atazadeh, Kalantari, Rajabifard, & Ho, 2017; Atazadeh, Kalantari, Rajabifard, Ho, & Ngo, 2017a) discussed the possibility of using BIM for modelling 3D land administration and ownership boundaries. Where Drobež, Fras, Ferlan and Lisec (2017) also explored application of 3D representation for 3D cadastre under different local context. All their work pointed out the challenges in current land administration process, and the importance of integrating 3D information. Mahdjoubi, Moobela and Laing (2013) proposed procedures for accurate and fast services provided by real estate sector. They applied BIM and laser scanning technologies to achieve fast capture of building structure and modelling, which is proved to be helpful by real estate professionals through qualitative surveying approach. Kara and Oosterom (2018) identified the type of analysis that can be employed for property valuation under the context of Land Administration Domain Model (LADM). They also discussed the significance of integrating 3D analysis with property valuation, and performed analysis using dataset of the Netherlands. As a new technology emerged from architecture and construction side, BIM has also been widely employed in building performance, energy efficiency analysis and sustainability analysis (Eleftheriadis, Mumovic, & Greening, 2017). While in the work of Encinas and De Herde (2013), they assessed the thermal comfort of 9 apartments in summer through sensitivity analysis. Natephra, Motamedi, Yabuki and Fukuda (2017) presented a method combining thermal information and BIM model for indoor thermal comfort modelling. They also provide visualization of thermal conditions over time, proposing a straight-forward way of identifying changes. The integration brought new insights for design and management phase in building life cycle.

Previous studies have applied to explore and discuss the necessity and potential of integrating 3D information in property valuation. Yet they focused more on the legal perspective, or only unilateral experiment on how BIM or 3D information could contribute for property valuation, especially in the context of China. Hence in this study, the potential of BIM on modelling property prices will be explored and discussed.

### 2.2.3. Factors influencing property value

This section aims at summarizing the influential factors of property prices found in different researches and documents. The related literature and locations of case studies, as well as their main findings on the factors, are listed in Table 1. One thing worth mentioning is that the approaches for quantification of indicators varied by research, which is difficult to illustrate or directly compare. Thus, in this table, the indicators that are found significant will be listed using the author's own term and definition.

Table 1 Review of related studies on influential factors of property price

| **Author(s)-Year** | **Location of study area** | **Application of RS/BIM** | **Models used for analysis** | **Main findings about influential factors** |
|---|---|---|---|---|
| D'Acci (2018) | Turin, Italy | None | MRA | Distance to the city center<br>Quality of the site not clearly defined (green, shops, streets, buildings, agreeable pedestrian streets, etc.) |
| Saptutyningsih (2013) | Daerah Istimewa Yogyakarta, Indonesia | None | MRA (hedonic price model) | Level of CO, ln plot area, ln building area, ln distance to school, ln distance to hospital, ln distance to supermarket, ln distance to restaurant, ln distance to city the centre, dummy variable of closeness to garden |
| Kay, Noland, & DiPetrillo (2014) | New jersey, America | None | MRA (hedonic price model) | Distance to nearest study station, distance to NYC station, social-economic characteristics (population density, single family/small or large multifamily, median income, average SAT math score, etc.), violent crime rate, park accessibility |
| Liman et al. (2015) | Minna, Nigeria | None | MRA (hedonic price model) | Type of house, size of the house, number of rooms, number of bathrooms, the age of the house, the condition of the house, year house was sold, the location of the property, distance to CBD, availability of facilities |
| Song, Liang, Lin, Wang, & Wu (2017) | Beijing, China | None | MRA (hedonic price model), spatial regression model | Mixed land use of commercial and service facility land, mixed land use of industrial land, mixed land use of public administration and public services, mixed land use of open space, transportation |
| Du & Huang (2018) | Hangzhou, China | None | MRA (hedonic price model) | Log distance to wetland, log distance to city centre, log distance to West Lake, log distance to Qiantang River, log distance to city complex, school, number of bus routes, green coverage, floor area ratio, parking space ratio, age, log units of apartments, quality of developers, quality of property management |
| Wen, Bu, & Qin (2014) | Hangzhou, China | None | MRA (hedonic price | Building age, external environment, inner environment, property management, sport |

| | | | | |
|---|---|---|---|---|
| | | | model), SWM | facilities, universities nearby, living facilities, education facilities, subway nearby, traffic condition, distance to Wulin Square, distance to West lake, Distance to Qianjiang New centre |
| Hui & Liang (2016) | Guangzhou, China | Not specified | Spatial models and SWM | Structural attributes (Area, floor, elevator)<br>Urban landscape views (Road, park, river)<br>Amenities (railway, bus stop, bank, hospital, post office) |
| Wen et al. (2014) | Shenzhen, China | None | MRA ("Spatial error model in mass appraisal" is the term used in this study) | Area, the number of streets with close proximity to the property, width of the property's proximity to the street, height, vacancy rate, depth of the commercial property (meters), level of appraisal divisions |
| He et al. (2010) | Beijing, China | None | MRA (hedonic price model) | Distance to CBD, floor area ratio, land price, existence of facilities nearby, existence of rail transits nearby |
| Helbich et al. (2013) | Vienna, Austria | 3D point-based analysis of solar radiation | MRA (hedonic price model) | Floor area, floor, age, time of sale, log road network distance to park, log road network distance to subway, solar radiation |
| Tomić, Roić, & Ivić (2012) | Zagreb, Croatian | DTM, digital relief model (DRM) | none | Visibility |

(MRA: multiple regression analysis; SWM: spatial weight matrix; Ln: Natural logarithm; Log: logarithm)

From a review of related literature, the indicators will be used in the questionnaire in this study and are summarized in Table 2. Based on the cultural consideration and the own experience of the author, "Fengshui" was added only to experiment whether this type of traditional belief is valued by people.

Table 2 Selected factors

| Dimension | Name |
|---|---|
| Factors with 3D information | Noise |
| | Daylighting |
| | View of green space |
| | View of nightscape |
| | Air pollution |
| Locational factors | Distance to CBD |
| | Distance to metro station |
| | Distance to the business centre |
| | Distance to hospital |
| | Distance to high school |
| | Distance to the main road |
| | Distance to express way |
| | Distance to park |
| Physical factors | Area of the apartment |

| | |
|---|---|
| | The floor of the apartment |
| | Number of bedrooms |
| | Number of toilets |
| | Area per room |
| | Indoor decoration condition |
| | Indoor heating system |
| | Property fees |
| | With/without parking spaces |
| | Greening rate |
| Cultural factors | Fengshui |

# 3. RESEARCH METHODOLOGY

In this chapter, the methods and tools used to answer research questions and accomplish objectives are discussed. Data collection methods for both primary and secondary data are also described in this section.

## 3.1. Overall approach

In this study, a mixed approach combining quantitative and qualitative methods was conducted. Here the general approaches are briefly introduced, and detailed methodology is illustrated in section 3.3. Regarding sub-objective 1, literature review as a content analysis approach was used to gain background knowledge and identify indicators as input to later research. Primary data was collected by semi-structured interview with experts and questionnaire with open-ended questions during fieldwork. Interview with experts can give insights on the design of the questionnaire, as well as guidance to the processing of raw data. The questionnaire was used to acquire users' perception of indicators influencing property value and the importance of indicators. Snowball sampling approach of respondents was performed to acquire the preferences and opinions of target users. Secondary data including building structure, property prices and regulations was collected via real estate companies, government policies and regulations to understand local content. Data processing was done using statistical analysis to summarize general pattern showed in the interview and questionnaire results, including identification of indicators and assigning weights to indicators. BIM model was created from satellite images and architectural plan with the help of remote sensing techniques to perform analysis on 3D indicators. Two set of indicators were prepared for further analysis: one with 2D indicators and the other with both 2D and 3D indicators. With the help of statistical tools, two sets of indicators were tested and compared to verify whether to introduce 3D information into the valuation process is beneficial according to the users' needs. After the construction of framework, K-fold cross validation approach was adopted to assess the performance of this framework.

The detailed methodology will be described in section 3.3. Research matrix regarding each sub-objective is attached in Appendix 1.

## 3.2. Overview of the study area

Regarding the research problem and research objective, the study area was selected based on the criteria illustrated in table 2. As for the last criterion, the proposed data analysis methods referring to the regression model. As defined by Field (2013), there should be "a minimum sample size of 50+8k, where k is the number of predictors". In this research, with the potential 23 indicators listed in table 1, there should be at least 234 samples available.

Table 3 Criteria of study area selection

| Criteria | Rationale |
|---|---|
| The upward trend on the real estate market | Local people (potential users of this framework) have the need to estimate their property value. |
| Data availability | Satellite images, transaction price and other useful data should be accessible to conduct this research. |
| High-rise residential buildings | The study area should have high residential buildings to show and analysis price difference in height. |
| Enough samples | The study area should have enough samples to run the proposed data analysis methods. |
| Good scenic view | The different scenic view can affect the property value. With a good scenic view, such difference might be strengthened and better for later analysis. |

Based on these criteria, two residential buildings in Xi'an city were chosen as the study area. Xi'an is the capital of Shanxi Province, also the leading city in the northwest region of China. As the node connecting the route to West Asia, this city had been through a rapid development after the Chinese government issued The Belt and Road Initiative (B&R) strategy. Another booster for city development is the regulation targeting educated and high-quality human source, which lowered the cost to settle down in the city. These two government policies facilitated the development of the real estate market, resulted in housing price doubled in the last two years. In February 2018, Xi'an was promoted as one of the National Central Cities, which will simulate the development of the city. The study area is shown in Figure 2. The red boundary is the administrative boundary of the city, and the star represents the selected building. A total number of 132 apartments in the building were sold in 2018 with accessible price data. From the building, the park built for Xi'an China International Horticultural Exposition 2011 and the Ba River are visible.

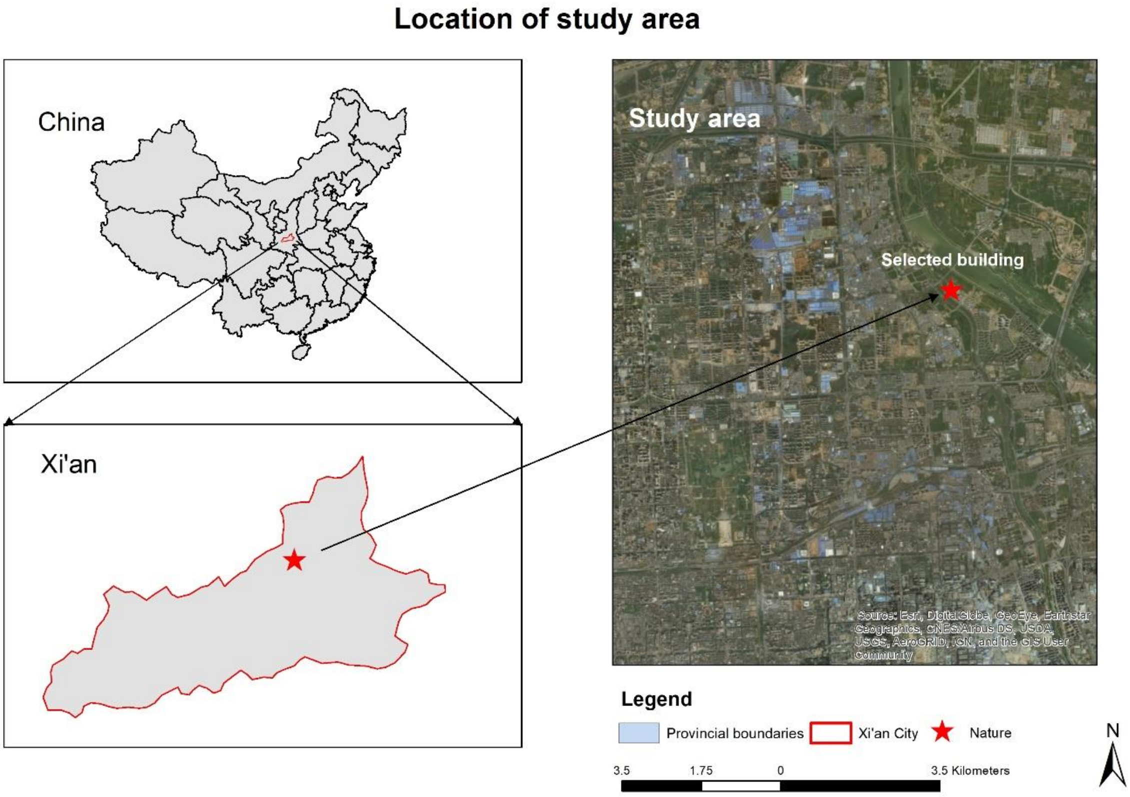


Figure 2 Study area

### 3.3. Research design

This research is conducted following the workflow shown in Figure 3.

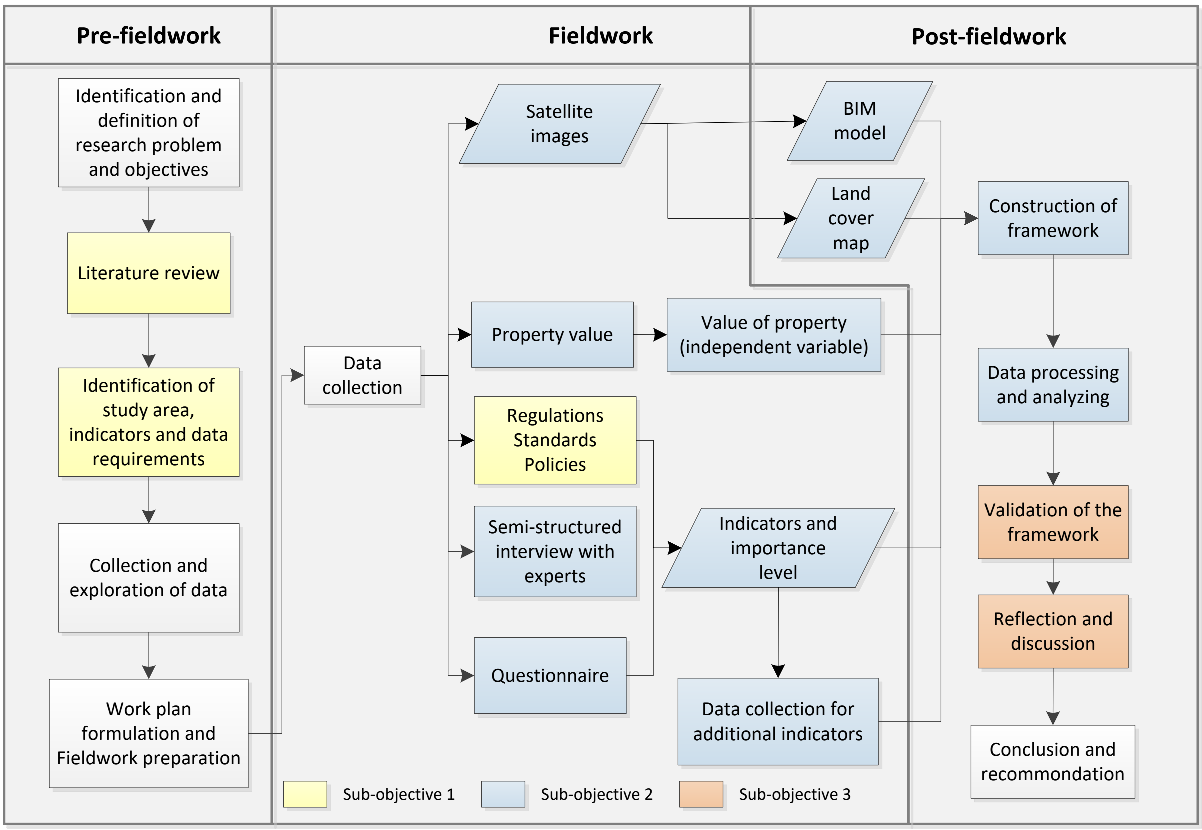


Figure 3 Research design workflow

### 3.3.1. Pre-fieldwork

In the stage of pre-fieldwork, the main focus is to address the questions posted under sub-objective 1 and get prepared for fieldwork. Therefore, a literature review was conducted from four aspects: the standards or indicators currently in use, the weight of existing indicators, methods proposed to measure these indicators, and the potential indicators from a users' perspective that can be added to enrich the valuation framework. The linkage between the indicators and methods to quantify them are also established in this process. Locational and physical factors can be measured using remote sensing data. As for other existing factors or potential indicators, concentrating on how remote sensing or 3D modelling techniques can help quantify them and provide guidance for later research design on data collection. Preparation before fieldwork contains searching and data pre-processing, formulating a detailed work plan, designing of questionnaires for the interviews and designing questionnaires.

### 3.3.2. Fieldwork

During the fieldwork stage, the main task was to collect primary data for construction of the framework. Primary data collection included semi-structured interviews with experts, questionnaire with respondents from the study area and focus group discussion with potential buyers.
Secondary data including property prices, satellite images, and additional data and documents were also collected during fieldwork. Property value was acquired from the website of Xi'an Municipal Bureau of Commodity Prices, where communities sold from October 2017 until now are published. Satellite images for constructing 3D models and extracting land cover information were provided by Prof. X. Li from Changan University.
Point of interest (POI) data containing all the facilities, schools and amenities was extracted using application programming interface (API) services provided by AutoNavi. Photos of the facades of the buildings were captured during a field visit to the selling department of the community to help in creating the BIM. Data availability and the source are summarized in Table 4.

Table 4 Data source and availability

| Data | Format | Area | How to collect | Purpose | Availability |
|---|---|---|---|---|---|
| Satellite images | tiff | 1 district (1m resolution) | Provided by Changan University | BIM and indicators | Available |
| Open street map | Point | 1 district | Open source | Indicators (e.g. roads, services) | Available |
| Building height survey | Polygon | City | Python crawler | BIM and indicators | Available |
| Property value | Polygon & Doc | Study area | Internet | Variables & validation | Available |
| Architectural plan | Doc | Study area | Field work | BIM and indicators | Available |
| Other indicators | Doc | Study area | Questionnaire and interviews | Indicators | Available |
| Relative information of the buildings | Doc | Study area | Real estate company | Indicators | Available |
| Cultural preferences of the residences in the city | Doc | City | Internet/interview | Indicators | Available |

Data preparation for later analysis was done during fieldwork to identify errors or missing data to allow the author to make correction in the field. Transcripts of interviews were summarized and translated to analyze experts' opinion on pricing strategies, existing problems, and future development. A list of indicators and rankings were concluded from questionnaires.

### 3.3.3. Post-fieldwork

The main focus of work after fieldwork is the construction of the framework and analyzing the relationship between indicators and housing price. Since the study aims at providing an easy-to-follow framework for users to evaluate their properties, analysis of data was split into two parts: one for the analysis of property prices distributed on the 2D plain, one for analysing the price difference caused by height. A simplified workflow of data analysis is shown in Figure 4. The list of influential indicators was summarized from the questionnaire. To quantify 2D indicators, ArcGIS and ENVI were used to derive locational factors (proximity to CBD and roads, etc.) and surrounding services of the study area. Since the study analyses the difference in property value caused by height, 2D indicators were only used to determine the base price of the area. Indicators related to 3D will be quantified using the BIM model and RS data in City Engine. Possible 3D indicators summarized from fieldwork such as a view of the scenery

from the properties were analyzed using the 3D analyst toolbox in ArcGIS and other related functions in City Engine.
Detailed methodology for data analysis can be found in section 3.5.

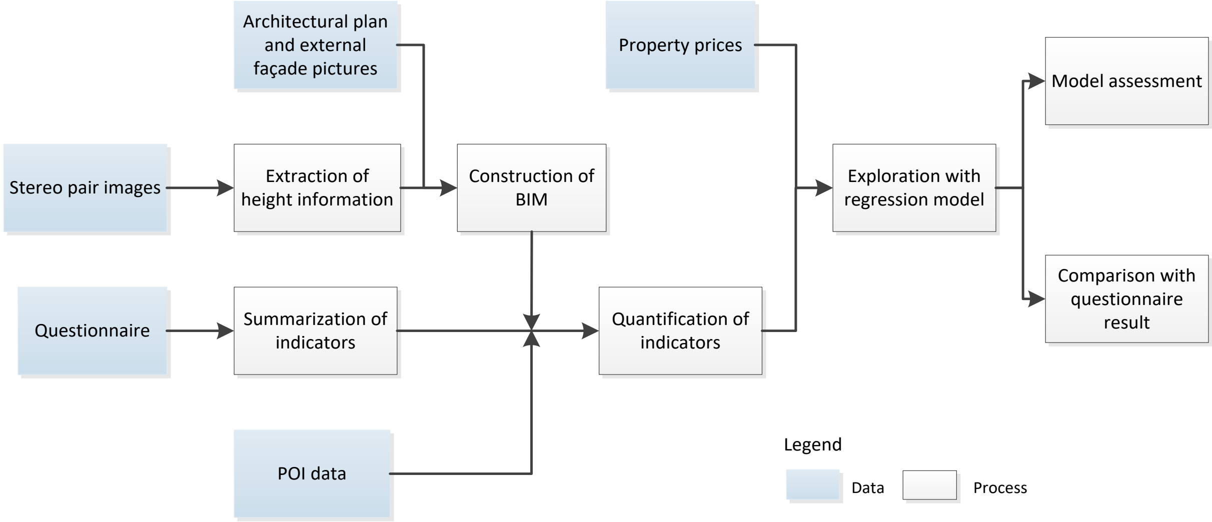


Figure 4 Proposed workflow for data analysis

## 3.4. Data collection methods

This section introduces the data collection methods conducted by the researcher. For primary data collection, semi-structured interview with experts, questionnaire and focus group were performed to gather useful data for both qualitative and quantitative analysis. Secondary data are collected using the desk research approach or literature review.

### 3.4.1. Semi-structured interview with experts

Semi-structured interview is an useful tool to gather attitudes and opinions while also "covers the previously unknown issues"(Wilson, 2014). It is also flexible to add follow-up questions when the respondents share an interesting point, which helps the researcher to get a more detailed explanation or insight.
The target respondents contain experts from the planning department, university and real estate companies. The aim of the interview and information of selected respondents are shown in Table 5. The interviews were recorded for later analysis after informing consent with respondents. The output of the interviews can provide insights for designing the questionnaire, selection of respondents, and key questions. Also, it provides guidance in case the questionnaire data doesn't reflect any general pattern either in the selection of indicators or in weights of indicators. Useful information about cultural preference regarding local content, such as preferred locations or stereotype on a specific area in the city, and the quality of neighbors were gathered through interviews. The questions used in the interview are listed in Appendix 2.

Table 5 Number of respondents and detailed information

| Target group | Aim | Respondents | Company/Department | Specialization |
|---|---|---|---|---|
| Experts from planning department | To understand the role of property value in planning processes and how they influence each other. | Interviewee 01 | Xi'an Survey and Mapping Institute | Survey |
| | | Interviewee 02 | | Survey&3D city |
| | | Interviewee 03 | Xi'an Qujiang New District Management Committee | Planning |
| | | Interviewee 04 | Xi'an Huadi Surveying and Mapping | Planning |

| | | | | |
|---|---|---|---|---|
| | | Interviewee 05 | Technology Co., Ltd. | Property valuation |
| University | To understand the state-of-art research on property valuation and integration of remote sensing and 3D technologies. | Interviewee 06 | Changan University | Land valuation |
| Real estate company | To understand what is commonly done in practice to valuate properties, including indicators, weights, methods, pricing strategy and its rationale. | Interviewee 07 | Gemdale Real Estate | Landscape design |
| | | Interviewee 08 | | Construction |
| | | Interviewee 09 | Jinhui Real Estate | Sales agent |
| | | Interviewee 10 | Ziwei Real Estate | Sales agent |
| | | Interviewee 11 | Greentown China | Landscape design |
| | | Interviewee 12 | Shanghai Industrial City Development Group Co., Ltd. | Sales agent |

#### 3.4.2. Questionnaire

Questionnaire targeting people from the study area was also performed to acquire opinions from the general public. It is a short online questionnaire with questions about their general impression on the real estate market in Xi'an, the motivation for purchase, indicators influencing the choice of residence, and the highest affordable price. Respondents were selected using snowball sampling from the city where the study area is located. It is a non-random sampling approach, with no requirements on a clear definition of sampling frame according to Bryman (2013). The researcher first had contact with a small group of relevant respondents and then diffuse the contact via their social network. The reason for choosing this is that researcher only has few connections with local citizens and is not able to get information like a list of potential participants. And this approach is easy and requires less investment in resources compared with other conventional approaches.

As for the tool used to spread this questionnaire, the researcher first tried an online map-based survey website called Maptionnaire. But during fieldwork, the website responded very slow in China, and the user interface was not comfortable according to the feedback of some respondents. As a result, the online platform "Wenjuanxing" was selected. It is the earliest and largest online survey, examination and voting platform in China. One important advantage of this platform is that it is perfectly compatible with Wechat, that anyone with a Wechat account can easily access the questionnaire. People are also familiar with this platform, which adds authority and reliability to the shared link of the questionnaire without being thought as "unknown and potentially harmful link". The complete questionnaire and the link are attached in Appendix 3. Examples of the user interface of "Wenjuanxing" platform is also attached.

Combining the indicators summarized from both the literature review and questionnaire, the indicators used in this study are listed in section 3.5, table 5. Three new indicators including a view of the waterbody and historical buildings and distance to tourist attractions were added due to the opinions of questionnaire participants. Indoor heating system, property fees, greening rate and a number of bedrooms were excluded because the value is the same throughout the gated community, which cannot contribute to solve the research problem. "Fengshui" as a cultural factor was excluded since there's no authoritative standards across the country.

#### 3.4.3. Focus group discussion

Focus group discussion with 7 buyers was conducted to help address the research problem. It is a powerful approach to interview several respondents at once and observe the discussion and people's reaction to a series of tightly defined questions(Bryman, 2013). The motivation for doing this is the "lack of communication" revealed by the result from questionnaire and interviews. To get more respondents, the questionnaire only contains 8 questions. The time needed to fill in the questionnaire is reduced, yet the content is limited. As for interviews, all the experts have different perspectives regarding their specialization. Thus, detailed comments from buyers and their willingness to pay for some specific indicators are missing. This focus group aims at comprehending users' preference on indicators with 3D information, their wiliness to pay for these indicators, and analysing the impact of 3D technologies on their selection and purchasing behavior. The respondents, who were the potential buyers were recommended by Dr. Xia Li. During the discussion, the moderator showed pictures of the scenic view and asked questions on how much the respondents would pay for such view and the reason. The detailed questions used in the focus group are listed in Appendix 4.

## 3.5. Data analysis

### 3.5.1. Modelling and visualization

Extensive methods and software are now applied in research for 3D modelling. This study requires model with moderate level of detail in order to conduct analysis. Therefore, using rule-based modelling and City Engine software is preferred. The modelling process is following the CityGML standards, which is an XML-based format issued by Open Geospatial Consortium (OGC). It is widely used for representation and exchange for 3D city models(Gröger & Plümer, 2012). Spatial information, semantics, and structure of the buildings can be easily defined and integrated into the model, which can be further used for analysis or visualization purposes. This standard defines 5 levels of detail. LoD0 is the coarsest level, with horizontal features (polygons, lines, etc.). LoD1 contains volume objects such as buildings and vegetations. All buildings are generalized in terms of vertical walls and horizontal roofs. In LoD2, roofs of buildings are more detailed represented with different shapes and angles, as well as structures like windows, doors and textures. LoD3 is considered as the most detailed level for shapes of objects with thematic details added to the building model. LoD4 is the level contains interior settings of the building(Gröger & Plümer, 2012). In this study, modelling the interior structure of the building does not help address the research problem, thus LoD3 is taken as the most appropriate level.

For later visualization and analysis purposes, aerial images of the study area with a 5km*5km area was used as a base layer. According to Cao et al.(2012), the average visual range in Xi'an is 6.4±4.5 km in 2009. Considering the increasingly severe air pollution in China and the limited resources that the author acquired, the assumed maximum distance that a person can see in this study is 2.5km. The satellite image used for this research was acquired from Gaofen 2 satellite in April 2017. This spacecraft carried 3.2m multispectral and 0.8m panchromatic cameras, cover the spectral range from 0.45μm to 0.9μm. Other than being used as base map for visualization, land cover classification was also performed, which is detailed in the next section.

For modelling of the building, architectural plan and pictures taken from fieldwork were used as reference, which can be found in Appendix 5. A feature class containing the type of apartments, shape, floors and building height was imported to CityEngine. Note, the height of each floor was assumed to be 3 meters since related data is not available. Then the 3D building was extruded according to the height attribute. In order to make the model more realistic, windows were generated on the external façade with predefined rules. For walls, the texture was assigned using the photo obtained during fieldwork.

For the surrounding area, building blocks with textures and roofs were generated. A feature class with shape and floors was imported into CityEngine as the base layer for surrounding buildings. The height was acquired by a group of GIS specialists from Harbin Institute of Technology, Wuhan University and Shenzhen University. They first generated 3D map through very-high resolution (VHR) stereo remote sensing image. Subsequently, they developed Python tool to automatically extract the height information from the AutoNavi map. In this study, surrounding buildings were extruded as blocks according to the height. After this, six types of texture images were selected from the assets provided by ESRI CityEngine tutorial, then assigned based on building height. In line with the Code for Design of Civil Buildings issued by Ministry of Housing and Urban-Rural Development (2005), buildings with 1-3 floors are defined as

low-rise residential building, 4-6 floors as multi-storey residential building, 7-9 floors as mid- rise residential building and 10+ floors as high-rise residential building. Arial image were assigned to the roofs to give a more realistic texture.
Transportation structures contains primary and secondary roads, were first digitized with google earth and exported to ArcGIS. Attributes were edited and then imported into the model.

#### 3.5.2. Quantification of indicators and regression analysis

As briefly introduced in section 3.3.3, indicators were quantified with the help of remote sensing techniques and 3D model of the study area. To quantify 3D indicators related with views, land cover map of study area was generated from classification of satellite images. The support vector machine (SVM) method was adopted, which is a non-parametric approach that is now widely used in image classification(Richards & Jia, 2013). Based on visual interpretation of the image, 8 classes including building with a concrete roof, building with a brick roof, factory/storage, road, tree, grass, water, and bare soil were selected. The classification process was performed using the SVM classification toolset in ENVI. Accuracy of classified result was assessed using the confusion matrix tool in ENVI, which compares the classified image with ground truth regions of interest (ROIs).
For data preparation, the quantification process for each indicator and its rationale are listed in Table 6.

Table 6 Quantification of indicators and its rationale

| Dimension | Name | Data source | Quantification methods/tools | Description and rationale for quantification |
|---|---|---|---|---|
| Factors with 3D information | Noise | Literature (Kim, Barber, & Srebric, 2017; Mak, Leung, & Jiang, 2010) | Simulation | As summarized from literature, there is a slightly decreasing trend on noise level with the height increases. Since there is no detailed data for the study area, the noise level will be simulated as high (0-30m), medium (31-60m), and low (60m+). |
| | Daylighting | Internet | Simulation in City Engine | |
| | View of green space | Land cover map | Viewshed analysis in City Engine | Different types of view from the property will influence its price. |
| | View of buildings | | | |
| | View of waterbody | | | |
| | View of historical buildings | | | |
| | Air pollution (PM2.5) | Literature (Ding et al., 2005; Zauli Sajani et al., 2018) | Simulation | From the conclusion summarized from literature, the concentration of PM 2.5 at low atmosphere slightly drops with the increase of height. Regarding the study area in this study, the concentration of PM 2.5 is classified as high (0-30m), medium (31-60m), and low (60m+). |
| Locational factors | Distance to CBD | POI data; a Master plan from the municipality; OSM | Euclidean distance tool in ArcGIS | Since POI data have too many redundancies, all irrelevant or repetitive records were manually filtered out. |
| | Distance to metro station | | | |
| | Distance to roads | | | Primary and secondary roads were selected from OSM dataset. Express way was also |

| | | | | |
|---|---|---|---|---|
| | Distance to express way | | | selected from OSM. |
| | Distance to hospital | | | Only hospitals with the highest certificate level "Sanjia" were selected. |
| | Distance to business centre | | | Business centres was manually digitized using the image of master plan downloaded from municipality website. |
| | Distance to high school | | | Only high schools have high admission score (ranked from 1st to 20th) in 2018 were selected and manually digitized. |
| | Distance to park | | | Regarding to the size of the park, entrances of the park were selected from POI data. |
| | Distance to tourist attractions | | | Only the ones defined as "world-class tourist attractions" in POI data were selected. |
| Physical factors | Area of the apartment | Real estate company | None | All data was retrieved from internet or real estate company and documented as table. $m^2$ |
| | Floor of the apartment | | | |
| | Number of toilets | | | |

After all the factors are quantified, regression analysis was performed using SPSS. The proposed workflow is shown in Figure 5.

The first regression model contains only 2D factors as covariates and average price (per square meter) of communities as dependent variable. The community here refers to the gated community in China, each covering an area of approximate four hectares. The price data was retrieved from the China Index Academy, a well-known database for property transactions in China (https://industry.fang.com/en/default.html). Three districts near study area with total of 178 transaction records were manually digitized. Since the 2D regression model contains 8 indicators, the samples are enough to perform regression analysis in SPSS. The model result reveals the relation between 2D factors and property prices, which will serve as the basis for the second model. Then the average price for the study area can be calculated using this regression model for 2D indicators. Then the dependent variable for the second model can be retrieved using the prices of apartments in the selected two buildings minus the average price. Together with the physical and 3D factors, the second regression analysis will be conducted. The result of this will be compared to examine if adding 3D indicators into the framework can help better model property value. The performance of the model, in this study, is the framework, will be evaluated by the mean value of accuracies derived from K times validation results(Hastie, Tibshirani, & Friedman, 2008). The data sets will be randomly divided into 10 equal-sized folds and perform regression analysis with 9 of the folds and left one for validation(Berrar, 2019). Estimated prediction error was calculated, which reveals "the average error committed in each fold"(Rodríguez, Pérez, & Lozano, 2010). In order to see if this framework satisfied the user requirements, the result were sent back to the respondents to ask for their feedback. Questionnaire with open-ended and closed questions was designed and shared to the contact information gathered from fieldwork. The questionnaire can be found in Appendix 8.

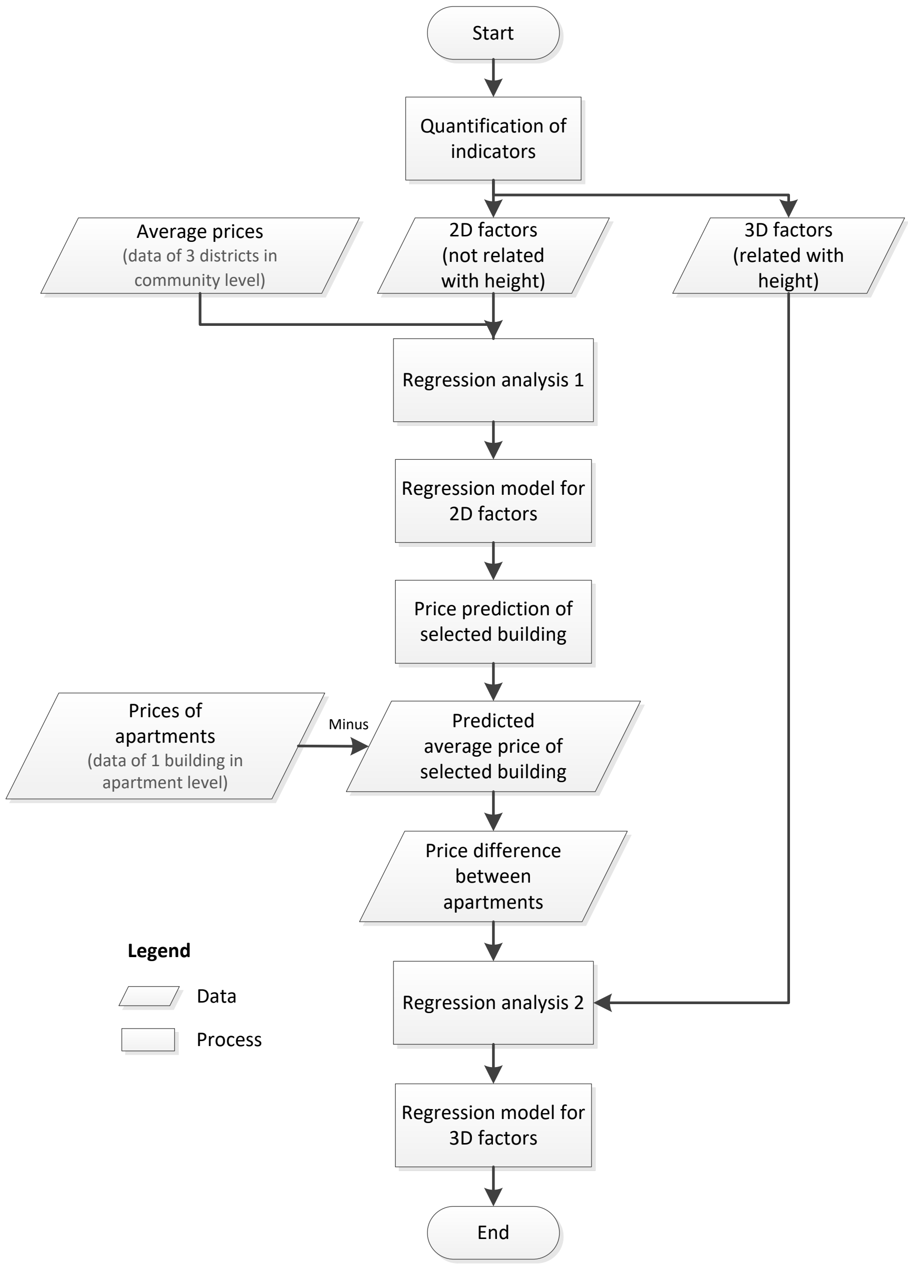


Figure 5 Proposed workflow for regression analysis

# 4. RESULTS AND DISCUSSION

This chapter presents the results of analysis. The current situation on the real estate market and government regulations were discussed from the result of the literature review and interview with experts. The process from land acquisition to the sale was stated based on interviews with experts from the planning department and university. Different criteria for property valuation were concluded from interview results. User requirements for residence were summarized from questionnaires. Results of two regression models and its validation, the BIM model of the study area and visualization were also presented. Last but not least, reflection and discussion regarding to the objectives of this study were stated.

## 4.1. The current situation on the real estate market in Xi'an and government regulations

The average property price in Xi'an slightly decreased from 2013 to 2015, then started a rapid increase from 2016 to 2017 according to the annual report published by National Bureau of Statistics of China: Xi'an Investigation Team(2018). This drastic change was the result of a series of regulations issued from June 2015 to September 2018. The new party secretary also took office in December 2016, who accelerated the development of the local real estate market. According to the interview with experts from the planning department, important policies are listed in Table 7. Moreover, the summarized policy change during the time is stated below.

Table 7 Influential regulations targeting the real estate market

| Time | Title of the regulation | Highlights |
|---|---|---|
| 2015.06.25 | Several opinions of the municipality on promoting the healthy development of the real estate market<br>关于促进房地产市场平稳健康发展的若干意见 | Reduce housing stock<br>Facilitate real estate market<br>Loosen the standards for "Hukou" |
| 2016.06.26 | Opinions on resolving the real estate inventory to promote a healthy development of the real estate market<br>西安市人民政府关于化解房地产库存促进房地产市场健康发展的若干意见 | Reduce housing stock<br>Facilitate real estate market |
| 2016.12.31 | Notice of the municipality on further promoting the healthy development of the real estate market<br>西安市人民政府关于进一步促进房地产市场持续平稳健康发展有关问题的通知 | Cool down the market (Restrain the increase on price)<br>Impose restrictions on speculators<br>Suppress the illegal housing agencies |
| 2017.04.18 | Opinions of the municipality on further strengthening management and maintaining healthy development of the real estate market<br>西安市人民政府关于进一步加强管理保持房地产市场平稳健康发展的若干意见 | Limit the source of second-hand housing transaction based on year of ownership (at least 2 years)<br>Implement the price declaration regulation |
| 2017.06.28 | Notice of the municipality on the adjustment of policies related to housing transactions | Further limit the source of second-hand housing transaction based on year of |

| | | |
|---|---|---|
| | 西安市人民政府办公厅关于调整我市住房交易政策有关问题的通知 | ownership (at least 5 years)<br>Limited purchase (people with at least 2-year record for individual income tax are allowed to buy) |
| 2017.09.13 | Notice of the municipality on further stabilizing the development of real estate market<br>西安市人民政府关于进一步稳定住房市场发展有关问题的通知 | Strict purchase limitation<br>Price limitation<br>Implement "Two 20% principle" |
| 2017.12.07 | Regulation of municipality on housing projects for talents<br>西安人才安居办法 | Offer subsidy to a targeted group (to attract elites to settle in the city) |
| 2018.03.30 | Notice on further strengthening the management of commodity housing sales<br>关于进一步加强商品住房销售管理的通知 | Implement "Yaohao" policy to restrict illegal purchasing behavior |
| 2018.06.23 | Notice on further regulation of housing transaction order<br>关于进一步规范我市住房交易秩序有关问题的通知 | Force the real estate company to supply a certain amount of housing at once<br>Notarize the "Yaohao" process and give priority to households with rigid housing demand |
| 2018.09.14 | Plan on deepening the supply-side structural reform of housing supply<br>西安市深化住房供给侧结构性改革实施方案 | Implement "Two 20% principle" and give priority to households with rigid housing demand |

Since the policies are not the focus of this study, there will be less discussion but only a brief introduction as background knowledge to support later analysis. To summarize, there was a dramatic price increase in the property price in Xi'an since 2016. This was due to the lowered standard on "Hukou" (the certificate for residents in the city) and a limited supply of land from June 2015 regarding the interview with experts (interviewee 4 and 5). From December 2016 till now, the municipality initiated several regulations emphasized on controlling price, suppressing illegal housing agencies and limiting second-hand housing transaction businesses. Two important regulations published in September 2017 and March 2018 strongly depressed the market by limiting purchase, housing price and "Yaohao" policy. Purchase limitation filtered out people who owned multiple houses, subsequently pushed the supply towards people who were really in need of residence and lower the demand. The price of a newly constructed housing project must be approved by the government before it went for sale. "Yaohao" policy is basically a lottery where every qualified households are randomly selected to gain the qualification to buy the apartment. This regulation also set a restriction on real estate companies and forced them to sell at least 50% of the total apartments to these households. It is clear to see the core of such regulation is to solve the housing problem for people with urgent need. As a result, the market gradually stabilized and the increase rate on price went down.

Current real estate market is still companied by an intense and flustered atmosphere. With such a huge demand for housing, one common scene is that as long as a new housing project enter the market, all apartments can be sold out in one day. This also has to do with the panic among citizens caused by rapid price growth. "Too many real estate speculators came to Xi'an and pushed up the price. A lot of local people are afraid that if they don't buy it now, they cannot afford it in the future", said by one sales agent. This comment is also commonly agreed by other interviewed experts.

Until now, the average price almost doubled compared with the price in early 2016. Most of the interviewed experts from the real estate company and planning department stated the main cause for this change was the implementation of "Hukou" policy since 2016. There is a considerable amount of demand for housing due to this policy, yet the pace for constructing supporting facilities is slower than the construction of housing projects and the inflow of young elites and working population. Therefore, building supporting facilities and planning for educational resources will be the focus in the future. Since September 2017, property prices are controlled by the government. Hence, only the properties sold after this date were selected for data analysis.

### 4.2. From land acquisition to sale

As illustrated in the last section, the housing price in Xi'an are strictly controlled by the government. There are several government departments involved in the process from land acquisition to final sale. The procedures are shown in figure 5, which are summarized from the opinions of experts from the planning department and real estate companies (interviewee 1, 2, 5 and 7).

There are three departments participating in this process. Xi'an Land and Resource Administration is in charge of land supply. When grant lease to real estate companies, they will add standards that must be fulfilled, including greening rate, floor area ratio (FAR), minimum hours of sunlight in winter, etc. Then the company does their schematic design, calculation on profit and other factors, then propose the prices of each apartment to Xi'an Bureau of Commodity Price. This department will check the proposed price based on these criteria:

a. The highest price, lowest price and average price of the housing project.
b. The average price of surrounding housing projects who can compete with this one.
c. The cost of construction based on the building material, structure, man-made landscape, etc.
d. The increase rate (no more than 2% comparing with previously reported price) or maximum price of undecorated and decorated apartments (when the housing project is new with no previous records).

Normally the price reported by real estate companies is higher than the price assessed by the Bureau of Commodity Price. Not only because the companies want to make more profits so they bargain with the government, but also the government wants to control the price of a certain area to prevent unaffordable price. Then the government reject the price and ask the companies to adjust it. This loop will end until the government and real estate companies come to an equilibrium point. Then Xi'an Municipal Bureau of Housing takes over the job and grant the certificate for advance sales of commodity houses after assessing the project. Finally, the apartments are ready for sale.

To simplify the loop mentioned before, the government gives three numbers as feedback of rejection, including the average price, the minimum and maximum price of the project. The housing project being constructed by the real estate company need to calculate these three prices and meet the price proposed by the government. As a result, the adaptation strategy of real estate companies is to reduce the cost on construction in order to obtain profit. Another commonly used trick is to increase the price for private parking space and other additional products or services provided by the company. By doing so, they can still make a profit while not violate the required housing price.

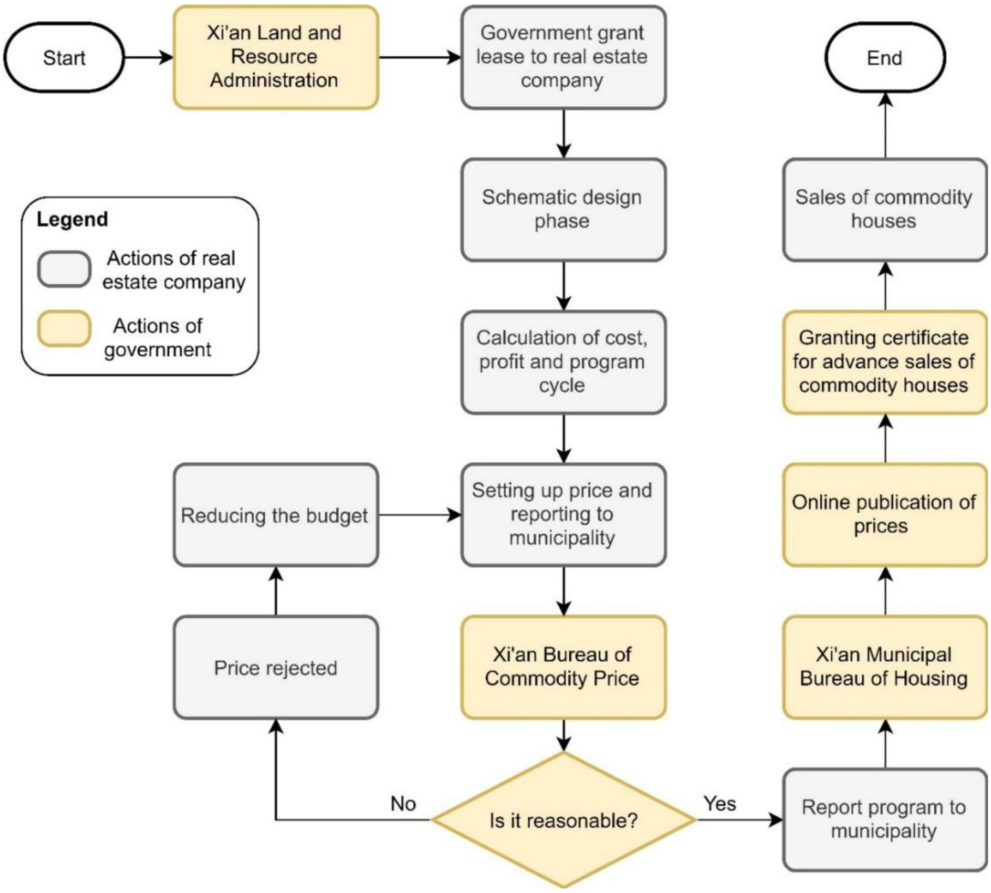


Figure 6 Current process from land acquisition to sale in Xi'an

## 4.3. Property valuation in practice

Property valuation in Xi'an is often done by the government, real estate companies and valuation agencies. The assessing criteria of the government are illustrated in section 2, thus this section will focus on the other two parts.

### 4.3.1. From the perspective of real estate companies

According to interviewee 7, 8, 9 and 12, there are a series of criteria for the company to determine the price of properties. Two fundamental principles for pricing strategy are: profit driven and from the macro level to micro level. Generally, projects with at least 8% of gross return can compete for the land and start the semantic design. In order to fulfill such a goal, the company needs to decide the best combination of products since there is a price gap between different types of apartments. There are five types of commonly-seen housing: house, stacked villa (3-6 floors), medium rise (7-9 floors), medium-high rise (10-18 floors), high rise (above 18 floors). The average price (per $m^2$) goes down following this sequence.

As stated before, the final price sold by real estate companies should not violate the proposed price. Since the government does not have enough time and resource to assess each apartment and set the price, the proposed price only contains three numbers: the maximum, minimum and average price. The average price is influenced by general condition (macro level) of the housing project: location, the average price of surrounding neighborhoods, the cost for construction, etc. When zooming in to the detailed price inside the project, there are several principles to assign different prices to different apartments. They first define the price rank of different buildings inside the housing project, then look further to each apartment, which is the micro level. The criteria for the ranking of buildings inside a housing project are summarized in Table 8.

Table 8 Criteria for property valuation on building level from the perspective of real estate companies

| Criteria for adding value | Criteria for reducing the value |
|---|---|
| In the center of the project | In the boundary area of the project |
| Near main entrance | Far from main entrance |
| Not adjoin with streets | Next to streets (the more the worse) |
| Fewer buildings block the view and sunshine | Blocked by other buildings |
| Away from the metro station | Near metro station |

Next step after ranking between buildings is the price difference between apartments. If it's a medium rise building, the price will increase from the first floor to the highest floor. When it comes to medium-high rise buildings, the price grows and reach a peak at 9-12 floors and decrease till the end. As for high rise buildings, the price peaks at 10-15 floors and decrease to both lowest and highest floor. This is because floor 2-4 might be covered by trees and resulting in less daylight. Floors in the middle of the building have a beautiful view, proper height to escape from the noise and enough sunshine. While higher floors might suffer from long waiting time for the elevators, noisy outside environment, and annoying sounds during windy days. When looking at the apartments on the same floor, apartments on the east side or with windows on both the south side and north side will have a higher price. The normal difference might be 60-100 yuan per square meter between nearby apartments. Before setting this price difference, the pre-stage department will do a survey on acceptable price and help for decision making.

It is clear to see that the pricing strategy of real estate companies is quite systematic. Though their pricing strategy has already taken some 3D indicators (daylight, noise, etc.) into consideration, it is not clear how each factor contributes to the price. One thing worth mentioning is that according to the interviews with interviewee 7 and 8, the price is dominant by locational factors and physical factors. Price difference caused by factors related to height are considerably less than those two. Whereas in the result of the questionnaire, this is not the users' opinion.

#### 4.3.2. From the perspective of valuation agencies

During fieldwork, the researcher could not get in touch with specialized experts in this field. But there are an enormous amount of valuation report and books accessible through the internet that can be used as a reference. The most authoritative one is the Code for Real Estate Appraisal issued by Ministry of Housing and Urban-Rural Development of the People's Republic of China (2015). According to this regulation, there are five commonly used methods for property valuation: sales comparison approach, income capitalization approach, cost approach, and hypothetical development method. It also stated the rule of thumb and principles depending on different purposes of valuation. The detailed methods and criteria for valuation are illustrated in the literature review chapter.

However, understanding the methods and principles requires a certain level of background knowledge on economics, planning and land administration. Another disadvantage of these conventional methods is that methods like the sales comparison approach and income capitalization approach have a fuzzy and less concrete definition. The method only provides a list of general standards and factors that should be considered, meaning that the real valuation process is strongly influenced by the people who conduct the valuation. As stated in the introduction section, this is also the public denunciation of the current valuation market. Last but not least, these conventional methods did not include 3D factors. This reveals the mismatch between current standards and user requirements.

### 4.4. User requirements reflected in the questionnaire

In order to achieve sub-objective 2, questionnaire and focus group discussion was conducted to collect data and to understand the requirements of users. The questionnaire got 186 responses, with 155 local responses and the left coming from other regions of China. About 66% of respondents are at the age of 16 to 30. So, the result might be biased by age, which is also the limitation of this research. But these young elites and working population are the target group of the municipality, meaning the questionnaire fits the local context.

Over half of the respondents holding a negative opinion on the sudden growth of property price. Words like “unaffordable”, “growing too fast” and “price does not match the income level” are commonly seen in the answers. According to the data released by National Bureau of Statistics of China: Xi’an Investigation Team (2017, 2018b), the growth on residents’ disposable income is 8.5%, and 13.7% growth on average housing price from 2016 to 2017. In this case, these expressions from respondents reflected the situation of the market. Among all respondents, around 75% of respondents had not bought apartments in the past three years and 75% of respondents will not purchase in the future three years. About 80% of respondents would purchase residences for their own living and use while only about 10% would buy apartments for investment. The majority (over 80%) took price below 15000 yuan/$m^2$ the highest affordable as the highest affordable price.

In the questionnaire, the influential factors and its importance level was used to acquire data reflecting user requirements. This is done by ranking the indicators based on the most frequent answer and the percentage of people choosing this.

Initially, the questionnaire used a 10-level Likert scale because the most commonly used grading system in China ranges from 0 to 100. A standardized scale from 1 to 10 is easier for people to understand and grade. However, the result of a 10-level Likert scale did not show explicit distinction between importance levels for some indicators. For example, the percentage of people was almost evenly distributed on several importance level. To show the difference, the level was translated into a 5-level Likert scale and the result is shown in figure 6.

Indicators including floor, air pollution, noise, daylight, view of green space and view of nightscape are related with height, which are the focus of this study. It is clear to see that air pollution, noise, daylight and view of green space ranked relatively high comparing with other indicators. Distance to freeway, number of toilets and fengshui are the least important factors according to the surveyed users.

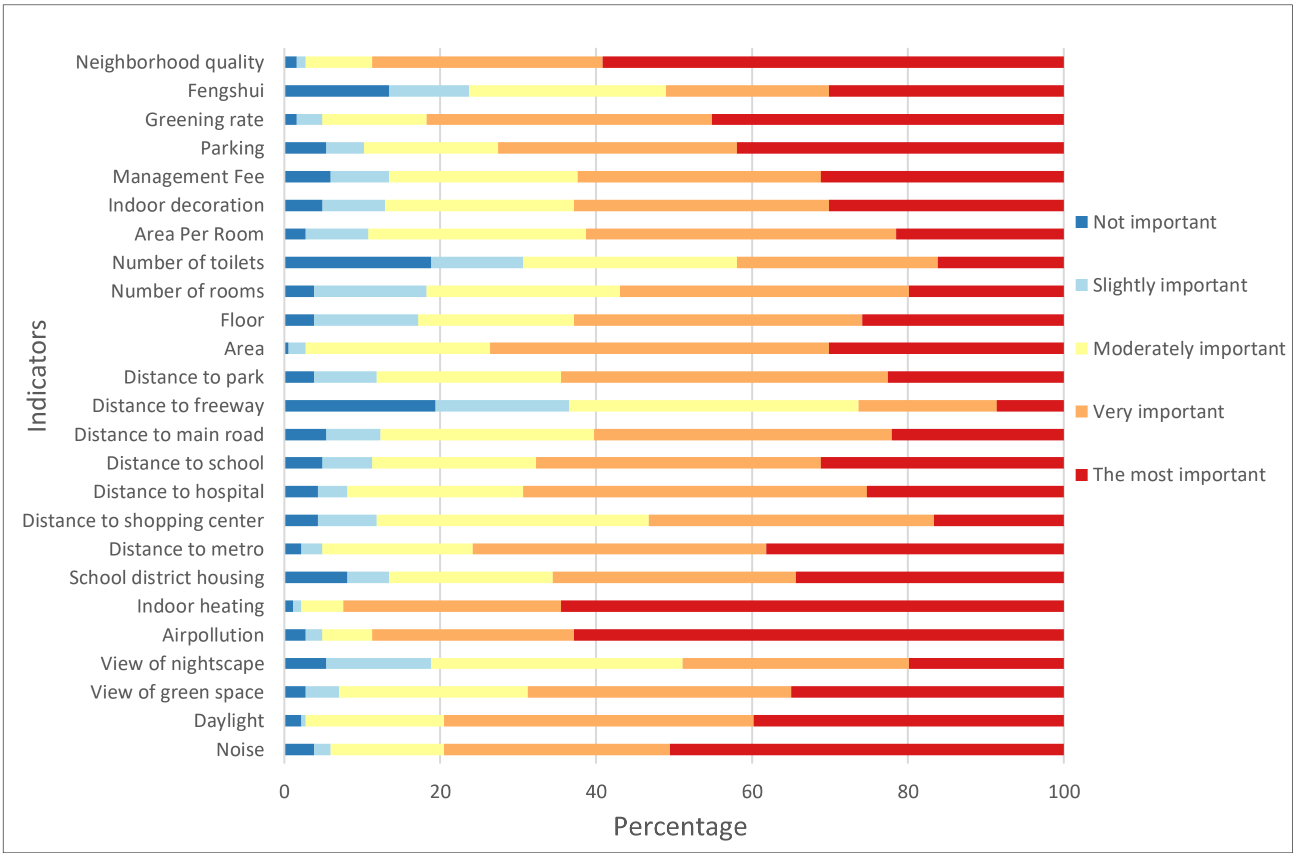


Figure 7 Users' perspective on the importance of indicators

### 4.5. Focus group discussion with buyers

Discussion in the form of focus group was adapted to acquire diverse and detailed views on how the participants value their property. The questions used for discussion can be found in appendix 4. Main objectives for these questions are identifying the preferred and disliked apartments, summarizing its characteristics and understand their willingness to pay for some specific factors.

Table 9 summarized all the qualities mentioned in the discussion. According to the objectives of the study, they are categorized into three dimensions. Dimension 2D contains the quality that can be quantified using 2D data, so does dimension 3D. It is clear to see that in 3D dimension, the participants focus on good quality of view from the apartments, revealing the high importance and demand for this factor. Noise is also a concerned quality since all participants showed a clear preference for a quiet living environment during the discussion. One disliked quality from the non-spatial aspects is "low neighbourhood quality". This was summarized from the discussing, containing no offensive meaning. It refers to a bundle of complicated neighbourhood characteristics including educational level, the appearance of neighbours, types of jobs of neighbours, etc. In a nutshell, a good impression of the neighbourhoods is important. Another disliked quality is away from metro station, which seems contradict with the result of expert interview summarized in Table 8. In previous result, the disliked quality was discussed from apartment level. However, here it refers to the community instead of a specific apartment. This reflects the difference in valuation criteria when thinking from different spatial scale.

Table 9 Preferred and disliked qualities of high-rise apartments

| Dimension | Preferred quality | Disliked quality |
|---|---|---|
| 2D | High greening rate<br>Supporting facilities<br>Clean environment<br>Good amenities<br>Near metro station | Low greening rate<br>Not enough supporting facilities<br>Dirty environment<br>Few amenities<br>Away from the metro station |
| 3D | View of green space<br>View of park<br>View of lake/river<br>Broad scenic view | View of expressway<br>View of messy surroundings<br>Being blocked by other buildings<br>View of chimneys/factories<br>Noisy outdoor environment |
| Non-spatial aspects | Safety<br>Quality of management | Unsafe environment<br>Too many dogs<br>Low neighbourhood quality |

During the discussion, the researcher showed several pictures of different types of views and ask the participants about how much extra they would be willing to pay for such view. For view of panorama or broad scene, they would like to give a maximum 1% extra investment on it. They would like to pay max 5% for view of green space, 5-8% of lake/river, and 10% for historical buildings. Xi'an is a well-known historical city with more than 3000 years of history. All the citizens are proud of this, as well as the remaining historical buildings. "*Imagine opening your bedroom window and enjoying the view of Daming Palace, how wonderful would that be. I'm sure most people won't be able to have such experience*", said by one of the participants.

Finally, the researcher showed the pictures to comprehend their preference on view from a different height. All the pictures were taken in front of the window of a living room on different floors. All participants preferred the view of higher floors than lower floors, while the degree of preference decreased following the descending of height.

## 4.6. The result of regression using 2D indicators

This regression using only 2D indicators, aiming at understanding the relationship between the locational factors and property prices. All indicators were first plotted with the independent variable to see if the relationship is linear. Plotted figures can be found in appendix 5, showing no strong relationship found between variables. The negative value is the result of standardization performed in SPSS. As a result, linear regression with backward method was chosen to model the price. Before running it, standardization of indicators was performed to reduce multicollinearity. Model summary and model parameters are shown in Table 9.

All the indicators were selected as input covariates (model 1), and the backward method in SPSS gradually removes the variables with no significant contribution to the model(Field, 2013). This process iterated for 7 times and stopped when all factors significantly contribute to the model. In this case, model 7 is the result of this initial run and the significant factors are the distance to high school/hospital/metro station/tourist attraction/CBD and business centre. However, when looking at the coefficients, distance to CBD and distance to hospitals have high VIF value, indicating the problem of multicollinearity. Thus, experiments were done to see if excluding one of the two can solve the problem. It was found that removing one of the two brings the multicollinearity problem with other indicators. Finally, both were omitted to avoid multicollinearity and the summary of the final model is shown in Table 11. The square correlation coefficient ($R^2$) of the final model is 0.113, meaning 11.3% of the variation in property prices can be explained by the factors. The F-ratio (F) calculates the improvement of using the model than not using it. In this case, the F-ration of the final model is 5.537, indicating an improvement of modelling property prices with the model. The influential factors for property prices in Xi'an are the distance to high school, metro station, tourist attractions and business centre. The coefficients of these variables are shown in table 11.

Table 10 Summary of the 2D regression model (initial run)

| Model | R | R Square | Adjusted R Square | Durbin-Watson | F |
|---|---|---|---|---|---|
| 1 (a) | .394[a] | .155 | .094 | | 2.523 |
| 2 (b) | .393[b] | .154 | .098 | | 2.755 |
| 3 (c) | .391[c] | .153 | .102 | | 3.020 |
| 4 (d) | .390[d] | .152 | .106 | | 3.341 |
| 5 (e) | .388[e] | .150 | .110 | | 3.737 |
| 6 (f) | .385[f] | .148 | .113 | | 4.224 |
| 7 (g) | .376[g] | .141 | .111 | 1.984 | 4.689 |
| g. Predictors: (Constant), Zscore(DistBusinessCenter), Zscore(DistTourist), Zscore(DistMetro), Zscore(DistHighSchool), Zscore(DistHospital), Zscore(DistCBD) | | | | | |
| h. Dependent Variable: Price | | | | | |

Table 11 Result of 2D regression model

| Model summary | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Model | R | | R Square | Adjusted R Square | | Durbin-Watson | | | F | |
| 1 | .337 | | .113 | .093 | | .1.923 | | | 5.537 | |
| **Coefficients** | | | | | | | | | | |
| | Unstandardized Coefficients | | Standardized Coefficients | | | 95.0% Confidence Interval for B | | Collinearity Statistics | | |
| Model | B | Std. Error | Beta | t | Sig. | Lower Bound | Upper Bound | Tolerance | VIF | |
| (Constant) | 8670.860 | 236.456 | | 36.670 | .000 | 8204.150 | 9137.569 | | | |
| Distance to high school | 642.586 | 333.816 | .194 | 1.925 | .056 | -16.290 | 1301.463 | .505 | 1.982 | |
| Distance to metro station | -817.727 | 282.634 | -.247 | -2.893 | .004 | -1375.582 | -259.871 | .704 | 1.421 | |
| Distance to tourist attraction | -814.428 | 283.990 | -.246 | -2.868 | .005 | -1374.960 | -253.897 | .697 | 1.434 | |
| Distance to business center | 708.472 | 346.802 | .214 | 2.043 | .043 | 23.964 | 1392.979 | .468 | 2.139 | |

Though the significance value of the distance to high school is slightly larger than 0.05, it is acceptable regarding such a low model fit. Excluding it will further lower the R square value. Based on the value of standardized coefficients, distance to metro station and tourist attractions are more important than the other two. Looking at the coefficient, properties near metro station and tourist attractions will have higher prices. Since the dependent variable is the average transaction price of the communities, the formula for modelling properties in Xi'an with 2D indicators is:

$$P_{\text{(community level)}} = 8760.860 + S\_DistHighSchool*642.586 - S\_DistMetro*817.727 - S\_DistTouristAttraction*814.428 + S\_DistBusinessCentre*708.472 \quad (1)$$

Where P is the abbreviation of the property price, and S stands for the standardized value.

The result of the 2D analysis was not as expected regarding the very low model fit. The reason behind this might be the price restriction regulation discussed in section 4.1. Price controlled by the government resulting in a more stable housing market and less difference between housing projects, since the purpose of government intervention is to seek a better distribution of resources. As a result, those properties with good location might have similar prices with the ones with bad location, reducing the effect of locational factors on housing prices. Another observation in this model is living near business centres is not preferable.

## 4.7. The result of 3D modelling and analysis

### 4.7.1. Image classification

To prepare data for viewshed analysis in 3D, land cover of the study area was classified using a support vector machine tool in ENVI. The classification result is shown in figure 8. According to the aerial image, eight types of land cover were selected using the Region of Interest (ROI) tool in ENVI. All ROIs were carefully selected while taking care of the number of samples per class. The reason for selecting different types of buildings is that though most of the buildings in the study area have a concrete roof, some of them are covered with bricks. Thus, buildings were divided into two class to avoid unnecessary mix in feature space. But only several buildings have a brick roof, resulting in a relatively smaller sample size.

The confusion matrix is illustrated in table 11. The overall accuracy of the classification is around 90.6%, and the kappa coefficient is 0.87. Looking at the classification result, paved roads on the north-east part was misclassified as buildings with a concrete rooftop. Moreover, the water surface was wrongly sorted as grass. This might be the result of shallow water area or algae/sediment-rich water content. Misclassification between grass and trees is probably caused by their similar spectral information.

For later analysis, two types of buildings and factories are merged into one macro class as "Buildings", serving as the data to perform viewshed analysis in the process of quantification of 3D indicators. Similarly, tree and grass are merged as one macro class "Vegetation".

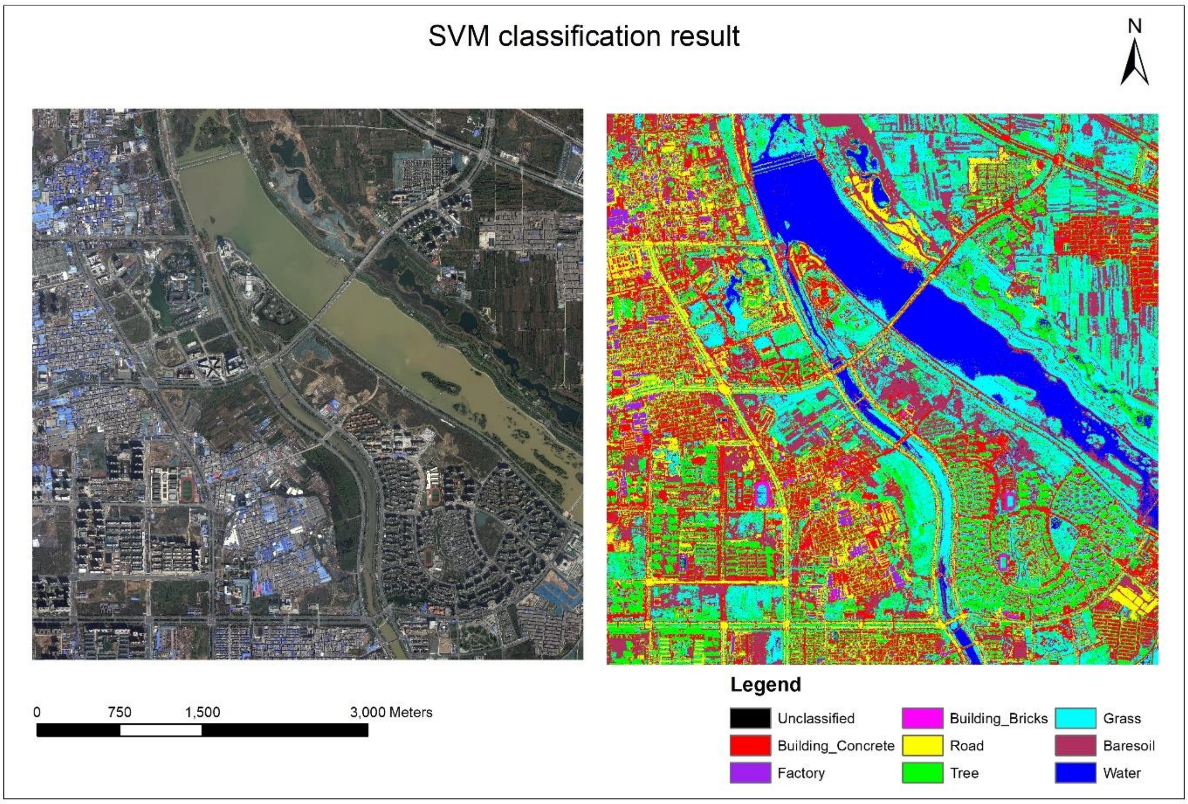

Figure 8 SVM classification result

Table 12 Confusion matrix

| Class | Ground truth(pixels) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Concrete | Factory | Bricks | Road | Tree | Grass | Baresoil | Water | Total |
| Concrete | 3075 | 0 | 0 | 1071 | 1 | 0 | 0 | 3 | 4150 |
| Factory | 3 | 6354 | 0 | 0 | 0 | 0 | 0 | 0 | 6357 |
| Bricks | 0 | 0 | 351 | 0 | 0 | 0 | 3 | 0 | 354 |
| Road | 0 | 542 | 0 | 3121 | 64 | 0 | 0 | 0 | 3727 |
| Tree | 0 | 0 | 0 | 0 | 266 | 543 | 0 | 0 | 809 |
| Grass | 0 | 0 | 0 | 20 | 991 | 1824 | 0 | 12 | 2847 |
| Bare soil | 7 | 0 | 47 | 5 | 0 | 0 | 3825 | 701 | 4585 |
| Water | 0 | 0 | 0 | 0 | 157 | 2 | 0 | 21780 | 21939 |
| Total | 3085 | 6896 | 398 | 4217 | 1479 | 2369 | 3828 | 22496 | 44768 |

#### 4.7.2. 3D modelling and visualization

The objective for visualization is to provide the users with a realistic and easy-to-understand way of seeing the built-up scene of the buildings, and how the prices of apartments vary with the change in height. In this study, the building will be visualised and analysed (study area) using LoD3 and the surrounding building blocks in LoD2. Explanations of LoD can be found in section 3.5.1. Figure 9 presents the BIM of selected building and visualization of surrounding environment. The selected building was developed in CityEngine by the researcher since no BIM model are available for the study area. Reference for modelling are the architectural plan of apartments and façade images acquired during fieldwork. Windows and facades were constructed according to its real position and texture. The surrounding building blocks were simplified with only random facades attached to its external wall. Full scene and layers are available on the CityEngine web scene viewer via link[1].

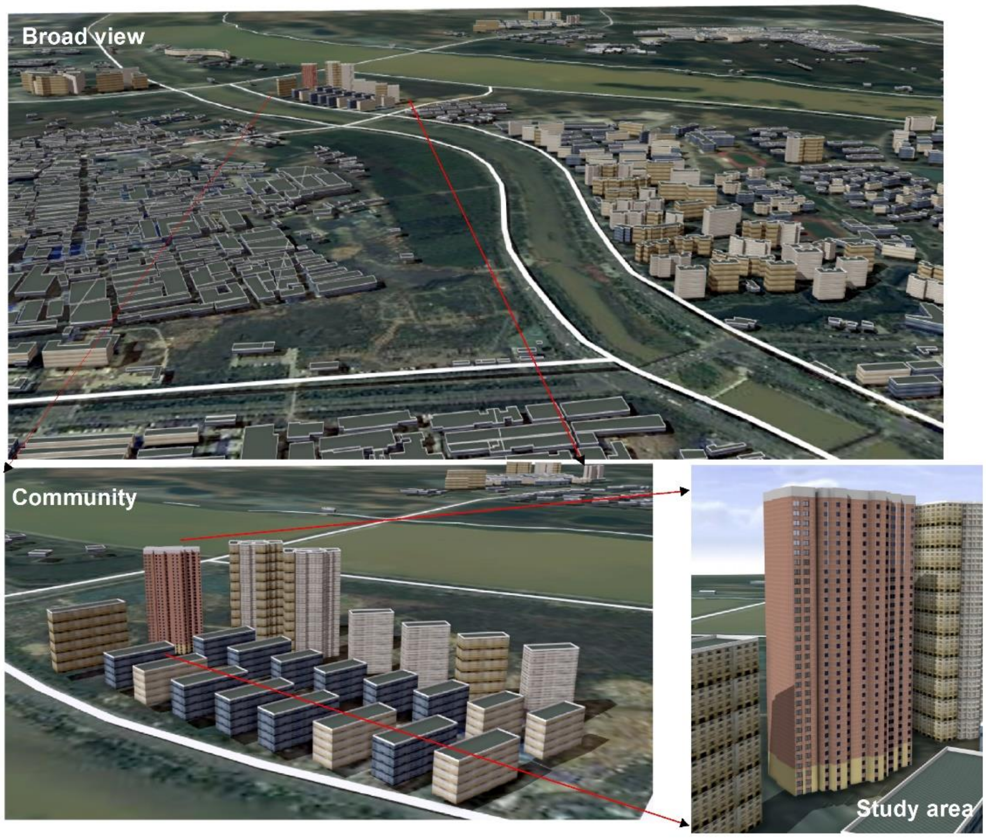


Figure 9 Captions of 3D visualization of the study area

The price of the selected building was visualized using CityEngine and ArcGIS pro, as shown in Figure 10. Colour range from yellow to red, corresponding the price from low to high. This building contains 4 types of apartments, labelled as apartment type 1-4 from left to right. Apartment 1 and 4 have windows on both the front and the back of the building, while apartment 2 and 3 are blocked by the elevator and staircase, with only the windows on the front.

It is clear to see a pattern of price change due to different apartment types and floors. For each type of apartment, the price increases from the bottom floor, peak at middle floors (15-18) and then decrease to the highest floor. Higher floors have relatively higher prices comparing to lower ones. When comparing by apartment type, apartments with both side of view (front and back window) have higher prices than those being blocked. The price difference for adjacent floors is around 40 yuan/$m^2$.

[1] http://bit.ly/2TMTvRU

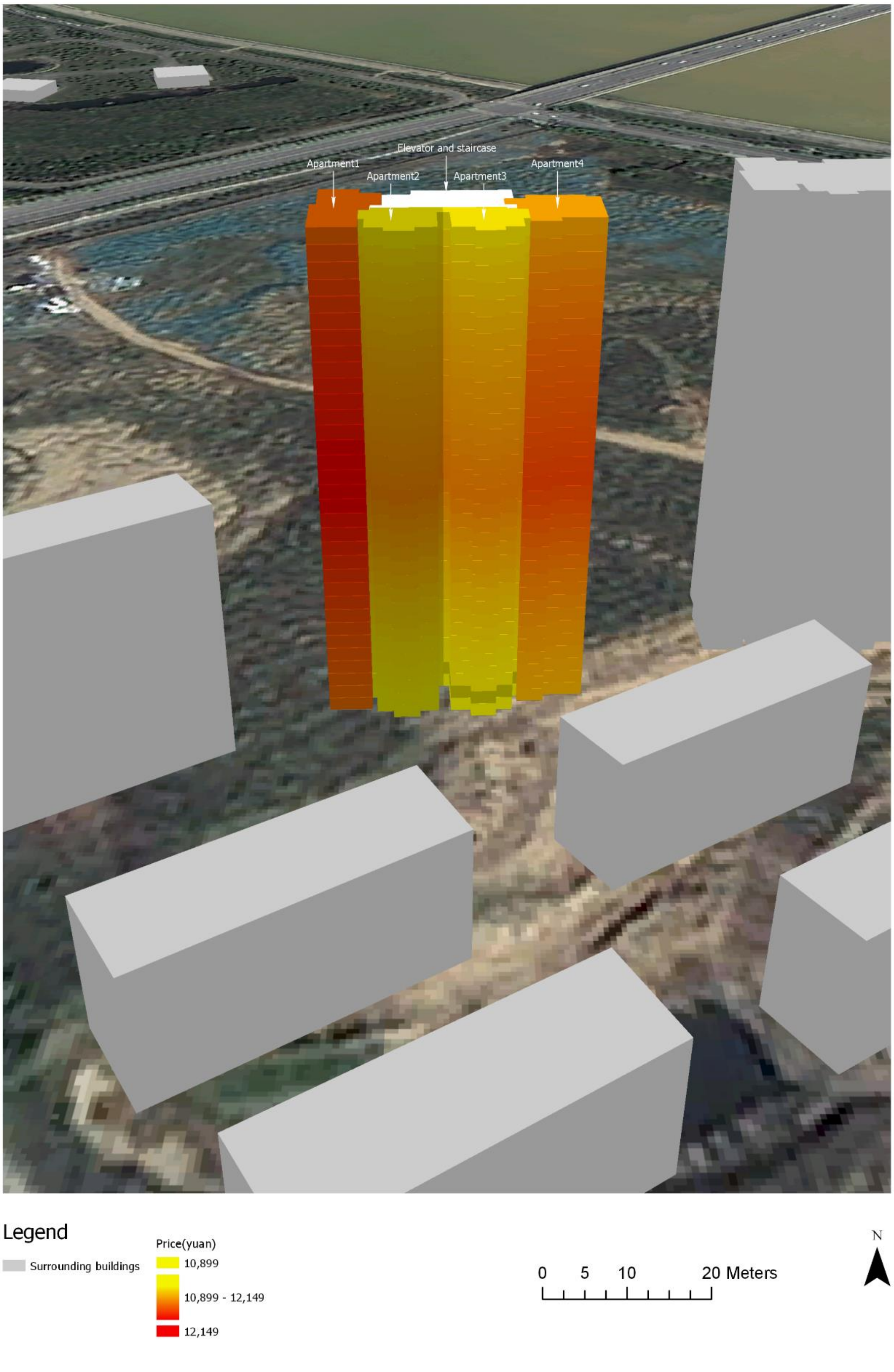


Figure 10 3D visualization of price

### 4.7.3. Viewshed and sun volume analysis

To quantify the indicators related to view, viewshed analysis was performed in CityEngine. CityEngine provides handy tools to interactively analyse the visible area to the point of interest. The visible and blocked area are labelled with different colours, which gives a quick and straight forward result. Various parameters are editable to show different scenarios. Horizontal and vertical angle of view from the observer defines the horizontal and vertical range can be seen by the observer. In this study, the simulated scenario is a person standing in front of the window of living room, looking straight ahead to south and north (no window on east or west in the real building). The horizontal angle was set to 150º and vertical was 60º. As stated in table 5, the assumed maximum distance that a person can see is 2.5 kilometre. By inspecting the viewshed analysis layer, CityEngine provides the proportion of each layer contributes to the total view. In the modelled building, apartment 1 and 4 contains both north and south side of view, while apartment 2 and 3 only have the view of the south. Thus apartment 2 and 3 contains only one side of view, and the view of apartment 1 and 4 is the sum of both sides. The classification result contains building, vegetation and water were used as input. The analysis was performed on each apartment and the visible area along with its percentage were summarized into excel.

Figure 11 gives an example of how the process looks like. Features with red colour are not visible and green ones are visible.

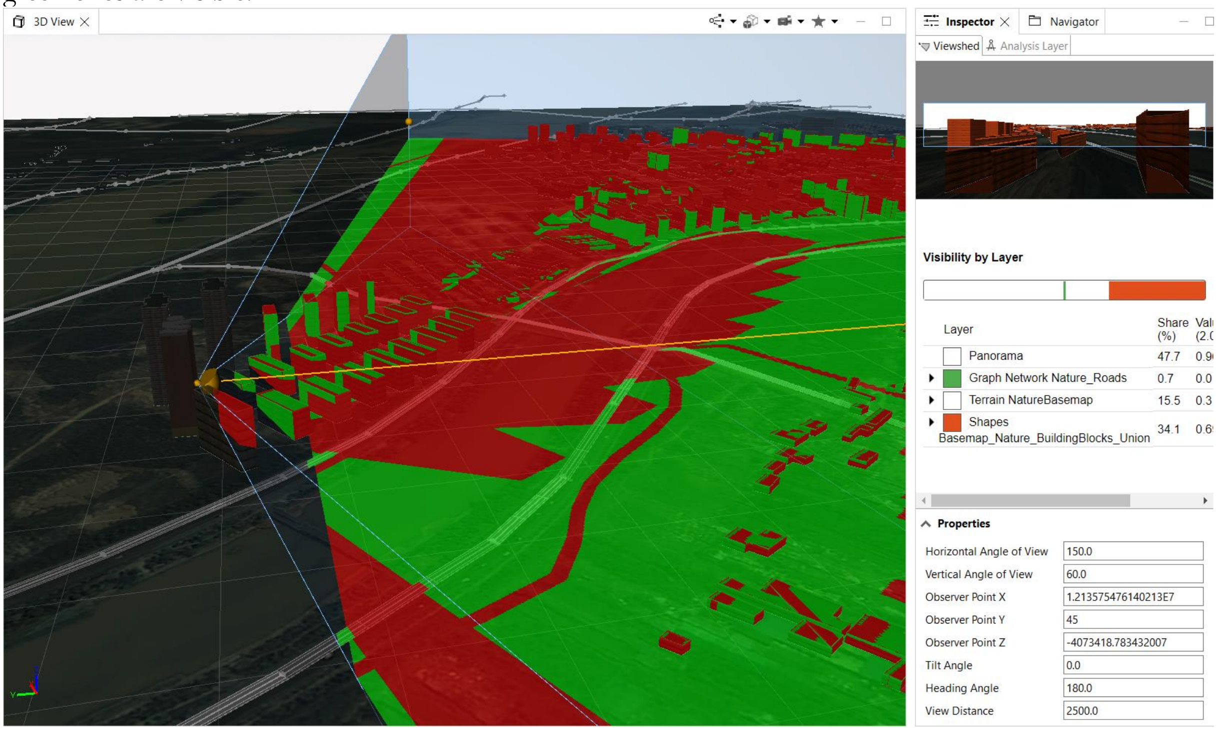


Figure 11 Screen shot of Viewshed analysis in CityEngine

When viewshed analysis is done, the sunlight duration of each apartment was quantified using sun volume analysis in ArcGIS. According to Ministry of Housing and Urban-Rural Development of the People's Republic of China (2018), the minimum sunlight duration should be no less than 2 hours in Xi'an on the day of The Great Cold(Chinese: 大寒). It is a solar term used in the lunar calendar, which begins around Jan 20th and ends on Feb 4th (Li et al., 2019). In this case, Jan 20th, 2019 was taken as the day to perform the analysis.

Sun shadow volume of the obstacle surrounding buildings were calculated and then intersected with selected building. When the volume of intersection is blocking the living room window on the front wall, then it is considered as being shaded by obstacle buildings. In the tool set, start and end date and time are entered, which in this case is on Jan 20th, 2019 from 8 am to 4 pm. Iteration interval is set to 1 hour, meaning every 1 hour the volume will be generated. According to the result, only 9 apartments were in the shadow at 8 am. These apartments have lower prices comparing with those not being blocked, yet identifying the causality needs further analysis with regression model. These apartments being blocked were categorized as 1, and the rest were categorized as 2. The sun shadow volume and the selected building are shown in figure 12.

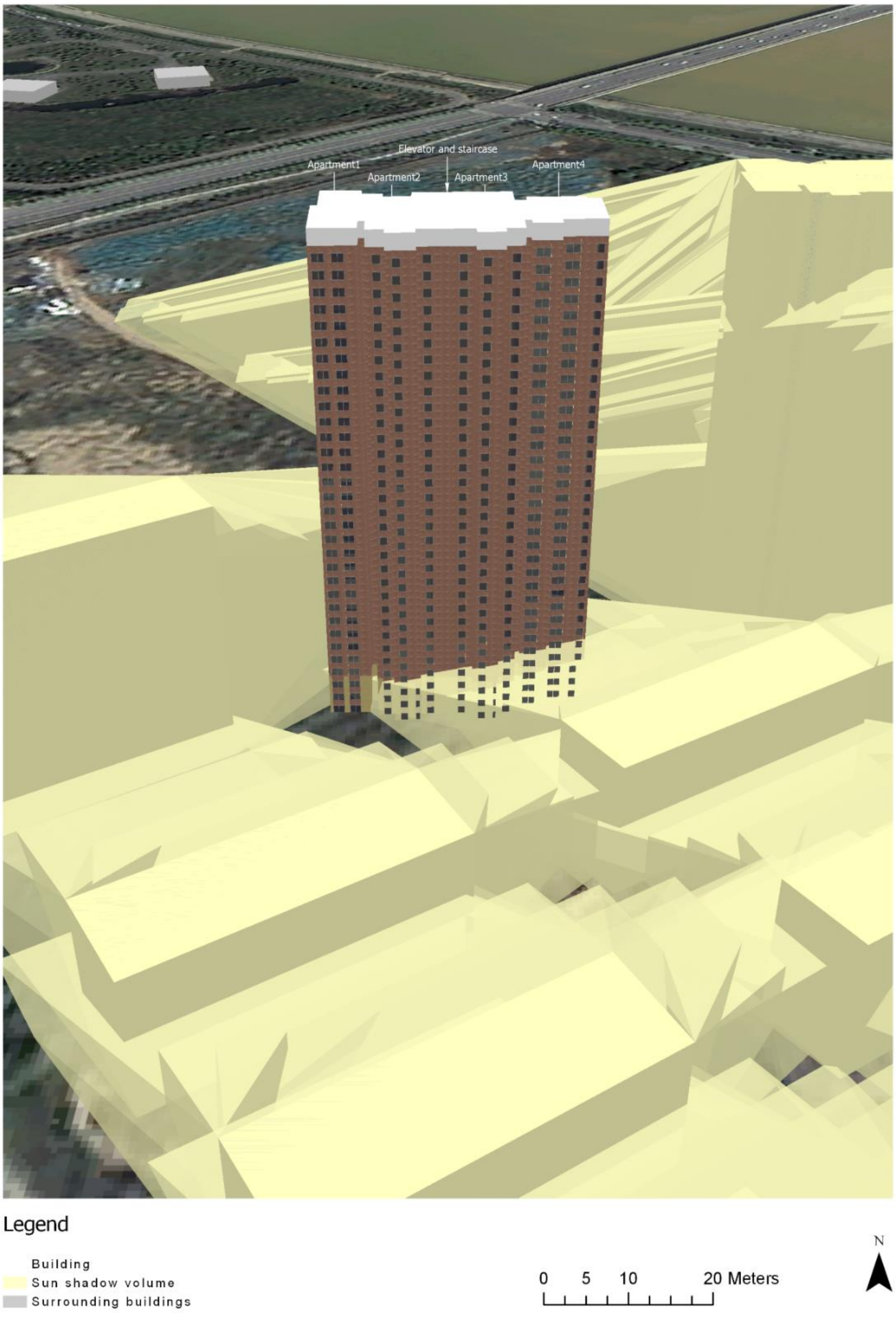


Figure 12 Sun shadow volume analysis

### 4.7.4. The result of regression using 3D indicators

After all the quantification of indicators were done, linear regression using SPSS was performed to analyse the relationship between 3D indicators and prices. According to the proposed methodology, the author first used the 2D regression to calculate the price of the study area (community level) as the predicted price. Then use the prices of each apartment to subtract the predicted price, and the result is assumed to be the contribution of characteristics of the property and 3D indicators on housing price. Using equation 1 in section 4.6, the predicted price of the study area is 8822.138 yuan/m$^2$. However, the real price is around 11000 yuan/m$^2$, showing the limitation of ignoring 3D factors. Similar to the regression analysis with 2D indicators, all factors were first plotted to identify theit relationship with the price. No significant relational curve was identified, thus linear relationship was adopted. The plotted variables can be found in appendix 6.

The result of regression using 3D indicatorsare shown in table 12. Physical factors including the area of the rooms and number of toilets were first imported to the model. Yet the result has high VIF value, indicating the problem of multicollinearity. Air pollution (PM2.5) was also excluded after the first run due to the high correlation with the noise. Regarding the literature, both indicators presents a slightly declining trend with the height increases. It is so small which is only around 10% decrease from the ground floor to 100 meter high. What's more, there are no widely agreed standards on how these two indicators distributed vertically, thus categorical variables were adopted to this simulation. Both indicators were categorized as high (0-30m), medium (31-60m) and low (60m+). This identical simulation resulted in a high correlation.

The R square of the model is 0.721, indicating the strong contribution and importance of using 3D indicators to model property prices. From the result, sun duration, view of buildings, vegetation and water are significant, among which view of the water is more important than the others regarding the value of Beta. All four indicators have a positive influence on prices, suggesting higher quality on these four factors will lead to a higher property price. Seeing from the value of standardized beta, factors related with view have higher influence than sun duration. This indicates lower price on lower floors might largely due to bad view instead of shorter time of sun duration.

The formula for calculating the added value contributed by physical factors and 3D indicators (referred to as 3D indicators in the equation) can be summarized as the equation:

$$P_{\text{(contribution of 3D indicators at apartment level)}} = 1403.252 + 186.195 * \text{Sun Duration} + +12.264 * \text{View of Buildings} + 11.461 * \text{View of Vegetation} + 44.116 * \text{View of Water} \quad (2)$$

Table 13 Model summary and coefficients of 3D regression

| Model summary | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Model | R | | R Square | Adjusted R Square | | Durbin-Watson | | | F | |
| 1 | .849 | | .721 | .712 | | .237 | | | 81.98 | |
| **Coefficients** | | | | | | | | | | |
| | Unstandardized Coefficients | | Standardized Coefficients | | | 95.0% Confidence Interval for B | | Collinearity Statistics | | |
| Model | B | Std. Error | Beta | t | Sig. | Lower Bound | Upper Bound | Tolerance | VIF | |
| (Constant) | 1403.252 | 152.821 | | 9.182 | 0.000 | 1100.848 | 1705.656 | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Sun duration | 186.195 | 64.168 | 0.145 | 2.902 | 0.004 | 59.218 | 313.172 | 0.885 | 1.129 |
| View of Buildings | 12.264 | 2.172 | 0.326 | 5.646 | 0.000 | 7.966 | 16.562 | 0.660 | 1.516 |
| View of vegetation | 11.461 | 1.921 | 0.400 | 5.966 | 0.000 | 7.660 | 15.263 | 0.490 | 2.042 |
| View of water | 44.116 | 6.387 | 0.515 | 6.907 | 0.000 | 31.477 | 56.755 | 0.395 | 2.534 |

### 4.8. The framework for property valuation in Xi'an

The aim of this study is to provide a framework for users to assess the value of their property. The proposed framework requires comprehensive data on spatial characteristics and 3D models in order to construct the database and perform analysis. Because of the massive amount of data, it is not easy to acquire and update the database. But it can be improved with the input of users. The required data for calculating the price, source, type of analysis to be applied and source of update are listed in Table 14. For the building blocks, shown as obstacle buildings in the 3D model for 3D analysis. Land cover can be acquired by either classification of remote sensing images or the survey data produced by the government.

Table 14 Source of required data for framework and update

| Data | Source | Analysis | Data source for update |
|---|---|---|---|
| Distance to high school | Local database | Euclidean distance | POI (API services provided by Google/Baidu/Amap) |
| Distance to metro station | | | |
| Distance to tourist attractions | | | |
| Distance to business centre | | | |
| Location of the property | User input | | User input |
| Building blocks (obstacle buildings) | Internet | Sun volume analysis & viewshed analysis | Internet (with Python scripts) |
| Sun duration | User input (orientation, floor and does it have windows on both south and north sides of the building)<br>Local database (land cover) | Sun volume analysis | User input |
| View of buildings | | Viewshed analysis | |
| View of vegetation | | | |
| View of water | | | |

After all data are available, the price can be calculated with the formula summarized from the two regression models presented (formula 1 and 2):

$$P = 10164.112 + \text{S\_Dist High School} * 642.586 - \text{S\_Dist Metro} * 817.727 - \text{S\_Dist Tourist Attraction} * 814.428 + \text{S\_Dist Business Centre} * 708.472 + 186.195 * \text{Sun Duration} + +12.264 * \text{View of Buildings} + 11.461 * \text{View of Vegetation} + 44.116 * \text{View of Water} \quad (3)$$

The calculation will be done automatically, and final price and value of each indicator will be reported to the users.

The framework has the following advantages:

- Not many requirements on data from the users (only location, floor, orientation and sides of the window).
- The process is easy to understand and follow.
- Indicators match the requirement of the users.
- This framework has uniform valuation standards and explicit criteria.

The proposed framework would be able to fulfil the needs including valuating a property with little requirements on user input, comparing characteristics of several properties with explicit scores, and contributing to the decision-making process for property purchasing. These are only the initial and basic function this framework can achieve. With further development, it can help users search all properties with desired quality or requirements on a specific indicator. It could also serve as the basis for large-scale property valuation and taxation purposes.

The prediction error of the framework and feedback from users will be discussed in the next section.

### 4.9. Validation and evaluation of the framework

Regression analysis contains 2D and 3D indicators were done to identify if integrating 3D factors could contribute to better modelling of property prices in Xi'an. The prediction result of 2D regression formula is 8822.138 yuan/m$^2$. Comparing to the real price, which is around 11000 yuan/m$^2$, the difference seems to be quite large. How the model performs with a different input dataset and how accurate is the model can be analyzed through k-fold cross validation(Hastie et al., 2008). For both regression model, the real price given by the government and predicted price of two regression models were imported to assess the estimated prediction error. The result for 2D regression model is 3610.051 yuan/m$^2$, and 572.4 yuan/m$^2$ for 3D regression model. By checking the real price, the price difference in one building is around 2000 yuan/m$^2$, where the price variance between apartments in different buildings is around 5000 yuan/m$^2$ or even larger. Since 2D regression model predicts the average price on community level, the estimation error is acceptable.

This formula was sent back with a small questionnaire to the participants in with the contact information collected during fieldwork, yet only 4 responses were received. The questionnaire for feedback can be found in appendix 8.

When being asked about how to valuate their property, two out of four participants would choose to ask the opinion of valuation agencies while the other two would rely on their own. All of them expressed the willingness to try online valuation approaches and showed trust of the result. Regarding to the indicators contained in the framework, one of them disapprove that price increases with larger distance to high school. All of them think distance to metro station is important, while three thought distance to tourist attractions is not important. For 3D indicators, all thought sun duration is important. Two respondents thought view of building is important while one disagree and the other thought price increases with larger view of building is incorrect. For view of vegetation and water, two thought it insignificant while other two respondents did not expect the appearance of these two factors.

Three respondents gave opinions on indicators should be taken in the framework, which are: indoor decoration condition, noise, quality of management, layout of the house, distance to bus station, distance to the airport, distance to primary school and distance to junior high school. Two respondents hold positive perspective on the application of the framework, while one suggested on differentiating the coefficient of indicators for different type of hosing projects.

Their trust of online valuation result revealed the need of such framework for property valuation. This framework proved combining 3D indicators could better model property prices. It also demonstrated the significance of some 3D indicators. Though in the end the respondents thought the framework is applicable, there are still many disadvantages. Similar to the suggestions about indicators should be contained, some of them were already identified through literature review and imported into questionnaire such as indoor decoration condition and quality of management. However, the samples for this study is from the same building, making it impossible to add indicators that are identical in one building.

## 4.10. Discussion

The results presented the current valuation approaches and valuation processes done by various stakeholders. The opinions of users were acquired through questionnaire and focus group discussion. Factors influencing property prices and their relationship were identified and analyzed, with a formula for property valuation summarized from the analysis. Discussions in line with the objectives and sub-objectives of this study are presented in this section.

The valuation approaches adopted in China were studied through a literature review. There are four commonly-used methods, namely comparison approach, income capitalization approach, cost approach, and hypothetical development approach. However, all of them are employed from economic concepts and approaches, which weakens the significance of spatial elements when thinking from the perspective of geographical science. While substantial researches on the hedonic pricing model had improved the situation and supported the significance of importing locational factors into property valuation.

The valuation processes and related valuation criteria from the perspective of various stakeholders were also discussed based on the result of expert interviews. Valuation done by real estate agencies is clearly profit driven. However, the consumer or property buyers have more requirements. Property as an immovable entity, connects the human activities to a location. With this close connection, the value of the property contains locational, physical and also emotional value. Thus, thinking from the perspective of user requirements and location is required in the assessment of property value. Current valuation standards are fixed to regulations, lacking the flexibility of absorbing new factors and opinions from the users. Taking a comparison approach as an example, it does not conduct direct analysis on the property itself but takes a similar sales record and modify the price based on a comparison between the two properties. Though it is applicable and less time-consuming, the process is unclear and fuzzy to the users. Not only the method itself is hard to understand by a layman, but the transparency of data source, decision-making process and quality of the valuers are implicit.

From the perspective of property buyers, they concern not only the monetary benefit brought by the property, but the living environment, comfort and a sense of belonging in the apartment (Y. Huang & Clark, 2002). Seeing from the result of the questionnaire, air pollution (PM2.5), noise, sun duration and view of green space are more valued by users than other indicators. In order to increase sales, the real estate companies already took 3D factors into consideration like floors and sun duration, yet not all were taken into consideration. They do not set the price according to the characteristics of the properties but taking the highest profit and regulations as priorities. Hence, how much value can be promoted by these 3D factors also remains veiled. The regression analysis using 3D factors found that sun duration and visibility factors significantly contribute to the price with positive impact. Analysis from the perspectives of users and real price both showed the importance of 3D factors, yet none were included in the valuation procedures.

For the government, the real estate market composes a large proportion of government fiscal revenue. Thus, quicker and better property valuation approaches can serve as a basis for taxation. Traditional approaches require a large investment in human resource and time during the survey and calculation processes. The standard for decision making is largely affected by the knowledge and experience of the valuer, revealing potential problems on less unified standards. The proposed methodology and the framework is based on the price data and land survey data, which are already stored by the municipality. During the expert interview with interviewee 1 and 2, they showed a demo of the 3D model of the city acquired by unmanned aerial vehicle. Their model does not reach to the details to specific floors, but 3D analysis as performed in this study can be easily applied. With the comprehensive data and better computation power, it is possible for the municipality to follow the methodology and perform valuation on more properties. Regular update of all the required input data is also convenient for the municipality. Thus, the proposed methodology and framework can support large-scale property valuation of the city with uniform standards, and further contribute to quicker taxation process by the government.

For the users, or so-called potential buyers for properties, it is important to know the price and the related quality. The proposed methodology and framework contain the indicators they think is important, which could provide them with the information they want to know in the final report. When they want to compare properties, this framework is also helpful for the decision-making. The explicit report on the value of each indicator provides a straight-forward way of assessing the quality of specific characteristics. Since all properties are valued using the same criteria, it is easy to directly compare the value of factors between the properties. Visualization and comparison with the 3D model are also feasible. The process and result are simple to understand comparing to the long and complicated valuation report produced by valuation agencies. The proposed framework still needs further development to make it accessible through website or apps, which is recommended in future work.

### 4.11. Limitation

Though this study had presented the significance of integrating 3D indicators into property valuation, there are several limitations emerged during the research processes.

The samples for both regression models are enough to perform analysis in SPSS, but still too less for a robust result. As discussed in the literature review section, valuation requires a large size of samples to support the comparison process. Since all properties have different samples, it is crucial to include more samples as much as possible to minimize the effect of specific factors or spatial autocorrelation. Regarding the interviews with experts, the price of housing projects under different real estate companies shares different valuation strategies. More samples would help in the generalization of the model.

Larger sample size could also promote the number of indicators, especially in the 3D regression model. Since there is only one building for 3D regression analysis, almost all physical factors are the same and being excluded. But seeing from the result of questionnaire, these factors are also important to the users. With a larger sample size, the effect of those excluded factors can be identified, and the fit of the model might improve.

Limitation of the framework comes not only from small sample size but also the difficulties on data acquisition and update. Xi'an is a unique example since the real estate market and the price are strictly controlled by the government. Though government interventions have negative affect on the result, the municipality collected data on first-hand housing transactions. Though the housing market is also controlled by the government in other Chinese cities, such a database is rarely seen in other cities. Also, the price of property is influenced by the changing regulations, interest, people's preference on housing and city. The unique spatial and temporal variation nature of property prices requires initial analysis when applying the framework in a new place. Such restrictions make the framework hardly scalable.

The BIM model constructed in this study is not quite detailed comparing with other dedicated projects online. Due to limitation of time, the model contains enough data to perform analysis and quantification of indicators, yet the power of visualization requires more exploration.

Due to limited time and resource, only four responses were received for model evaluation. More feedback from the user could bring more insights to improve the framework.

# 5. CONCLUSION AND RECOMMENDATIONS

In chapter 4, the result of the questionnaire, expert interviews, regression analysis, 3D model and visualization were presented. In this section, conclusions regarding the results and objectives of the study are demonstrated. Limitations of this study and recommendations for future research are also discussed.

## 5.1. Conclusion

This study proposed a framework for property valuation using 3D and remote sensing techniques. Mismatch of indicators were found between those required and valued by users and those taken by valuation standards. The factors taken by valuation standards focused on the physical and locational characteristics of the property. While for users who want to buy a house, they also require good quality on living environment and amenities. The significant increase of using 3D factors for modelling property prices were proved in the 3D regression analysis, indicating the necessity of introducing 3D factors into property valuation. The proposed framework still needs further development to make it applicable and accessible on apps or websites. However, it can serve as the basis for large-scale property valuation or taxation purposes with sufficient data and regular update.

***Sub-objective 1: To identify factors influencing property values through review of the literature and other related documents.***

Conventional approaches and indicators for property valuation in practice were identified through a literature review of international and domestic standards. Four commonly applied approaches were found, namely comparison approach, income capitalization approach, cost approach and hypothetical development approach. These methods focused on the physical factors and several locational factors of the properties, including area, floor, orientation, greening rate, land use, the structure of the building, year of construction, etc.

More factors related to spatial and 3D information were identified through a literature review of related researches. Floor area ratio, external environment of the building and quality of management as physical factors were identified by other researchers. Accessibility factors including distance to CBD, distance to public transport and distance to public amenities were found significant to price. Environmental amenities including parks, lakes and wetlands were also highlighted in research. Good educational resource nearby is another crucial factor. Several studies pointed out the view of urban landscapes (park, river) had a positive impact on property value.

***Sub-objective 2: To develop a framework for property valuation using 3D and BIM based on users' requirements.***

Indicators identified from literature and related documents were employed as input for the questionnaire to gather opinions of users. Semi-interview with experts and focus group discussions were adopted to acquire perspectives from various stakeholders. Based on the result and data availability, indicators were quantified with the help of remote sensing and 3D modelling. Land cover of the study area was classified using SVM approach and achieved an accuracy over 90%. Land cover class including buildings, vegetation and water were imported as the basis for 3D analysis. BIM model of the study area was constructed using an architectural plan and pictures of facades collected during fieldwork. After all indicators were quantified, multiple linear regression analysis was performed to analyse the relationship between price and factors.

For users that are in need of valuing their property or the potential buyers, air pollution (PM2.5), noise, sun duration and view of green space are more concerned than other indicators. This reveals mismatch with the influential factors taken by valuation standards. While the distance to the freeway, the number of toilets and fengshui are the least important ones. Their wiliness to pay for view of green and water/lake ranged from 0-8% of the total price, emphising the high requirements and need for good quality of these factors. However, none of the 3D factors were included in current valuation standards.

Regression analysis using 2D factors found smaller distance to metro station and distance to tourist attractions have positive effect on property prices in Xi'an. While larger distance to high school and distance to business centre have negative effect on prices. Low model fit of the 2D regression analysis might be the result of government intervention on housing market in Xi'an. Indicators with 3D information were imported to multiple regression model to identify the influence of integrating 3D factors into property valuation on the basis of 2D regression analysis. The result of 2D regression have the model fit of 0.113, while 3D regression achieved over 0.7, which greatly increased the ability of modelling price variations on the vertical dimension. In the 3D regression model, sun duration, view of buildings, view of vegetation and view of water were influential, and all presented positive effect on property price. The result highlights the necessity of integrating 3D factors into property valuation.

The proposed framework for property valuation was then created. It requires the input from users and open-source data on characteristics of the properties. With this framework, one can easily valuate his property by entering only three factors: orientation, floor and does it have windows on both south and north sides of the building. Values of each factor and predicted price will be reported to the users, offering the opportunities of comparing the factors of several properties. Users could benefit from the explicit result in decision-making process on purchasing or selling the properties.

***Sub-objective 3: To evaluate the performance and limitations of the framework.***

The model was validated using k-fold cross validation approach, resulting in an acceptable estimation error and proved the feasibility of the model. Feedback of the users showed their need and trust for such framework, making the research meaningful from practical aspect. However, this framework was limited by the small size of samples, which forces some indicators being excluded from the framework like greening rate, indoor decoration condition, etc. More factors could be added to enrich the model and fits the need of users.

The proposed methodology and framework have the potential to serve as the basis for taxation purposes since the government retains extensive, sufficient data and source to perform analysis and regular update of the model. The application of the framework into websites or apps requires further development.

## 5.2. Recommendations for future research

The recommendations for future research are listed below.

- Future research could focus on reducing the error of the model and generalize the model to make it applicable in most Chinese cities.
- Different types of quantification and simulation approaches could be applied to better model the prices.
- Advanced techniques in CityGML need to be explored to further accelerates the modelling process.
- Valuation of second-hand housing is also a concerning issue that requires further research in order to serve taxation purposes.

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# APPENDICES

**Appendix 1 Research matrix**

The research matrix shown in table 8 details data collection methods, data analysis methods and anticipated results regarding each research objective.

Table 15 Research matrix

| Specific objective | Research questions | Data Collection method | Source/ respondents | Analysis method | Anticipated results |
|---|---|---|---|---|---|
| To identify factors influencing property values through review of literature and other related documents. | • What are the influential factors, methods, and models identified by researchers in the field of remote sensing and BIM to support property valuation?<br>• What are the currently-used indicators for residential property valuation in China? | Literature review | Online literatures and government documents | Content analysis | List of indicators (used in both practice and research) |
| To develop a framework for property valuation using 3D and BIM based on users' requirements. | • What are the users' requirements for factor influencing property values and their importance?<br>• What are the methods used in RS and BIM to quantify those indicators?<br>• What is the relationships between factors and the property value? | Semi-structured interviews with experts;<br>Questionnaire;<br>Secondary data collection. | Experts are from: university, real estate company and planning department.<br>Respondents for questionnaire are selected via snowball sampling approach.<br>Secondary data collection contains: government standards/regulations, building information about study area, etc.<br>Satellite image is provided by Changan University. | Categorize content of interviews;<br>Extract general pattern from questionnaire using SPSS;<br>Quantify indicators using ArcGIS and City Engine;<br>Statistical analysis of indicators and independent variable using SPSS. | List of indicators and its weights based on user requirements.<br>List of required data for each indicator.<br>2D framework and 3D framework. |
| To evaluate the performance and limitations of the framework. | • To what extent does this framework satisfy the needs of users?<br>• What is the strength and weakness of this framework? | Validation | Send the framework result back to the same respondent of questionnaire and experts and get their feedback.<br>Validate the framework part of the dataset. | Content analysis of feedback;<br>K-fold cross validation;<br>Statistical analysis. | Feedback from users;<br>Statistical result of validation. |

## Appendix 2 Questions for semi-structured interview

**Questions for experts from real estate companies**

1. According to your opinion, what are the most important criteria when trying to sell the apartments?
2. What are the methods you use to value residential property?
3. (First show the list of indicators) What are the indicators and its weights used in residential property valuation?
4. (Strategies relate to some floors have different price) What factors are considered when setting different price for different floors? (e.g. floors in the middle gets higher price)
5. What are the standards used to quantify this difference into monetary value?
6. Do you use 3D visualization when selling properties? How do the customers think about 3D model? (Do they think it's a good way to visualize or it's not helpful?)

**Questions for experts from planning department**

1. Do you use remote sensing data in planning? If so, have you considered the vertical dimension in planning?
2. How do planning decisions influencing property value? What kind of plan will cause this change? (metro, new business center, new school)
3. Under what circumstances will the planning department consider about property valuation? (Give examples like IT cluster, shopping mall…)
4. What data do you need for property valuation? Where do you get this information and when will you use it?
5. Are there any problems related with property values when implementing a planning decision? (management, compensation for reallocation, time consuming, etc.)
6. How do you think remote sensing and 3D can help improve the situation?
7. What might be the challenges when try to combine 3D with current planning processes/try to solve the problem mentioned above?

**Questions for experts from universities**

1. Do you often use remote sensing data in your research? What are the advantages and disadvantages?
2. What are the stare-of-art topics in the field of remote sensing and BIM?
3. What are the methods and procedures used for property valuation?
4. Have you ever considered 3D factors during valuation? If not, what 3D factors you think can be integrated in this process?
5. What do you think can be improved? Is there any missing information?
6. To your opinion, will it be beneficial if combine 3D information and platform (e.g.: BIM) in the process of planning and valuation? What will be the challenges?
7. What do you think is the emphasis of future researches on property valuation?

## Appendix 3 Questionnaire used during fieldwork[2]

1. Example of the user interface in "Wenjuanxing"


2. Questionnaire

Information sheet

This questionnaire is part of the research "Developing a comprehensive framework for property valuation using 3D and remote sensing techniques in China". It is carried out by Jingxuan Zhang, an MSc student studying urban planning and management in ITC, University of Twente.

The main goal of this research is to develop a framework for property valuation based on user requirements, with the help of remote sensing and 3D models. This questionnaire will help the researcher to understand the user requirements/standards on residence. The result will hopefully contribute to residential property valuation process in China.

You are invited to fill in this questionnaire on a voluntary basis. It will take you max. 15 minutes to fill.

The data used during this research will be maintained confidential and anonymous.

For any information about this research, please contact Jingxuan Zhang: j.zhang-8@student.utwente.nl

[2] Link: https://www.wjx.cn/m/29011292.aspx

1. The housing price in Xi'an had been through a rapid increase in the past 3 years. What is your general impression about the housing price in Xi'an? Please describe your opinion with short sentences.

   ______________________________________________________________________

2. Did you buy a house/apartment in the past 3 years?
   A. Yes
   B. No

3. Do you plan to buy a/an apartment/house in 3 years?
   A. Yes
   B. No

4. What would be the motivation for you to buy a/an apartment/house? (If choose C, please fill in your reason)
   A. For personal living.
   B. For investment (rent, sell, etc.).
   C. Others: _________

5. What are the factors you will consider when looking for an apartment? Please check the box following the factor you choose on the important scale of 1 - 10(1 is least important, and 10 is the most important). If you have other factors that is not contained, please fill in the blank spaces in the table and check the numbers as well.

| Name | Scale of importance | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Noise | | | | | | | | | | |
| Daylighting | | | | | | | | | | |
| View of green space | | | | | | | | | | |
| View of nightscape | | | | | | | | | | |
| Air pollution | | | | | | | | | | |
| Heating system | | | | | | | | | | |
| Distance to metro station | | | | | | | | | | |
| Distance to shopping center | | | | | | | | | | |
| Distance to hospital | | | | | | | | | | |
| Distance to school | | | | | | | | | | |
| Distance to main roads | | | | | | | | | | |
| Distance to express way | | | | | | | | | | |
| Distance to parks/lakes | | | | | | | | | | |
| Area of the apartment | | | | | | | | | | |
| Floor of the apartment | | | | | | | | | | |
| Number of bedrooms | | | | | | | | | | |
| Number of toilets | | | | | | | | | | |
| Area per room | | | | | | | | | | |
| Indoor decoration condition | | | | | | | | | | |
| Property fees | | | | | | | | | | |
| With/without parking spaces | | | | | | | | | | |
| Greening rate | | | | | | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Fengshui | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |

6. What is your age?
   A. 0 - 15
   B. 16 - 30
   C. 31 – 45
   D. 46 – 64
   E. Above 64

7. If you want to buy a/an house/apartment, which of the following price categories is acceptable to you?
   A. Price < 500000
   B. 500000 <= price < 1 million
   C. 1 million <= price < 2 million
   D. 2 million <= price < 3 million
   E. Price >= 3 million

## Appendix 4 Questions for focus group discussion

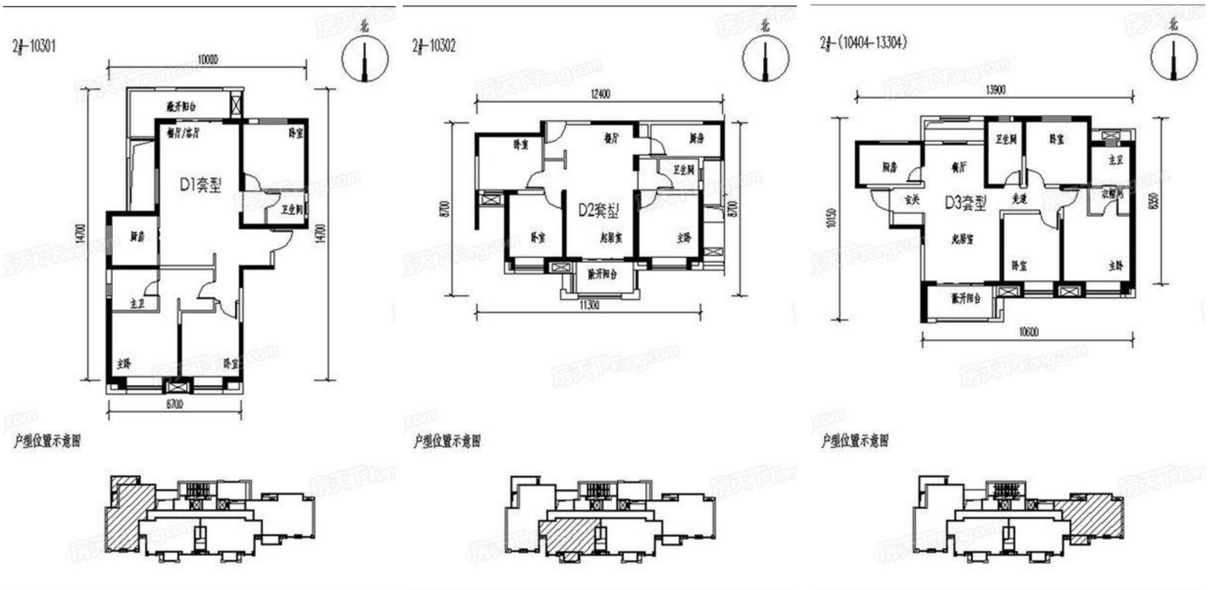
**Interview Guide for focus group**

1. What do you think of the residential property price growth in Xi'an?
2. What attributes do you value in a high-rise apartment? Why?
3. What kind of apartment do you dislike? Why?
4. Does your preference for housing change over time?
5. In your opinion, what are the reasons behind the price difference of apartments on different storeys? What are the factors related to the height you value when buying an apartment?
6. What kind of view do you most want to see/not want to see? Why?
7. How much are you willing to pay for these apartments on different storeys? (Show pictures of the south-facing balconies of the apartments on different storeys)
8. How much are you willing to pay for these different kinds of view? (Show pictures of different views, including green land, street, square)
9. Have you experienced 3D technology during your purchase, such as VR? Do you think the existing sand table, model room, and display area are enough for you to understand the whole scenario? Is it necessary for a 3D model?
10. In your opinion, what are the factors promoting the residential property price in Xi'an? What are your expectations for the future trend of Xi'an residential property prices?
11. Have you ever had a problem with the real estate developers' description after you bought an apartment? What impact does it have? (Examples, supporting facilities are not perfect/slow, the unreasonable design of the apartment)
12. Will the planning of Xi'an affect your housing choices? If so, what kind of planning will affect?
13. In the future, if you do housing choice, which administrative district will you choose? Why?

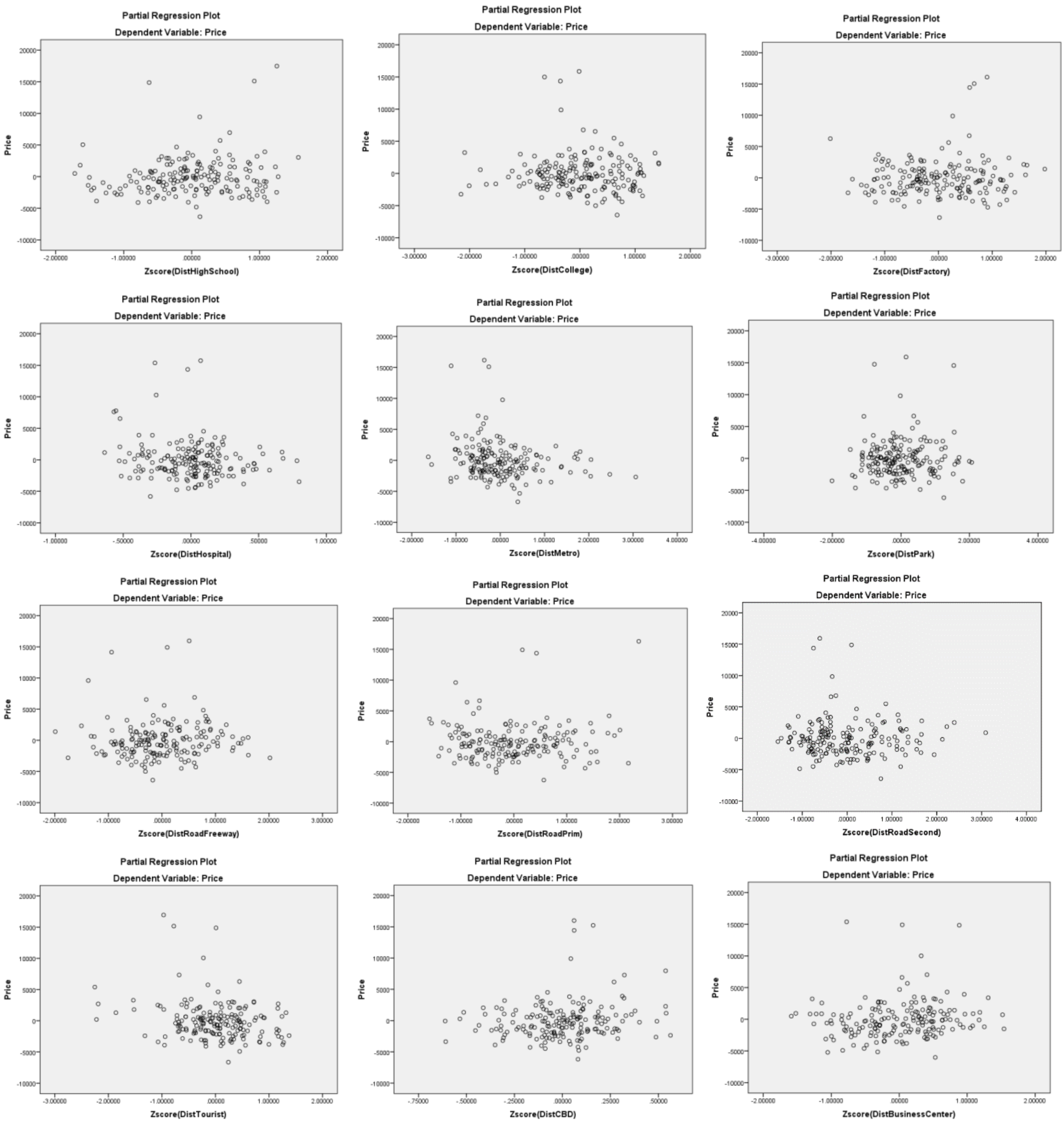
## Appendix 5 Architectural plan for BIM construction

1. Layout of surrounding buildings

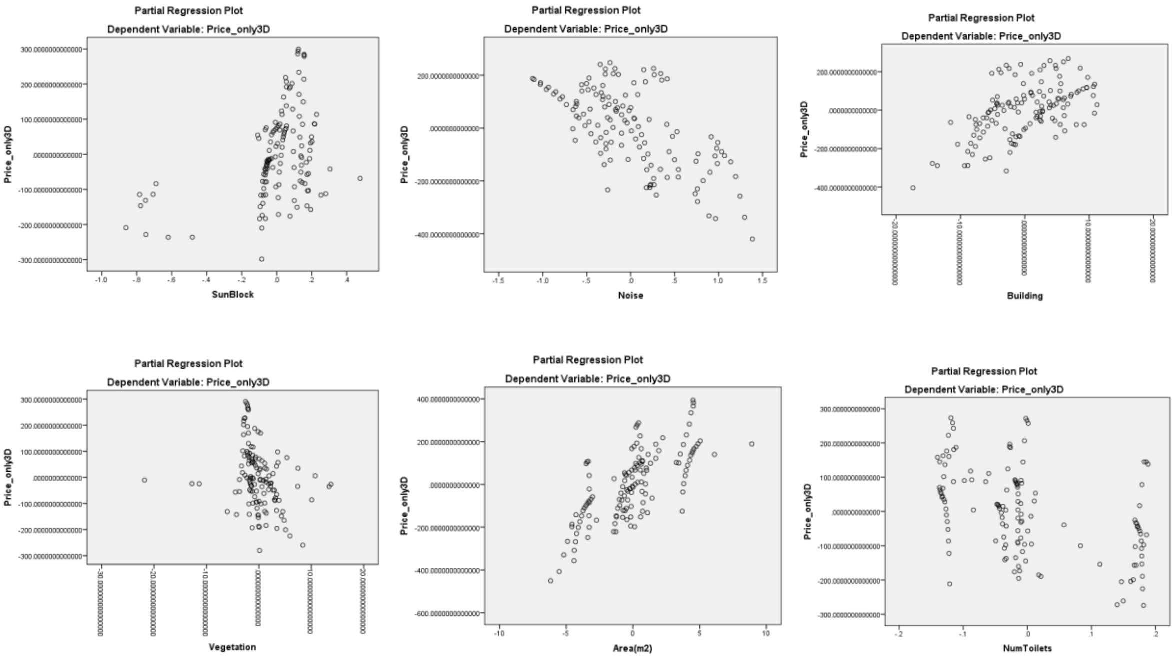

2. Architectural plan of the apartments



# Appendix 6 Figure of plotted 2D variables



# Appendix 7 Figure of plotted 3D variables



## Appendix 8 Questionnaire for collecting feedback from users

Information sheet

This questionnaire is part of the research "Developing a comprehensive framework for property valuation using 3D and remote sensing techniques in China". It is carried out by Jingxuan Zhang, an MSc student studying urban planning and management in ITC, University of Twente.

The main goal of this research is to develop a framework for property valuation based on user requirements, with the help of remote sensing and 3D models. This questionnaire will help the researcher to understand the user requirements/standards on residence. The result will hopefully contribute to residential property valuation process in China.

You are invited to fill in this questionnaire on a voluntary basis. It will take you max. 15 minutes to fill.

The data used during this research will be maintained confidential and anonymous.

For any information about this research, please contact Jingxuan Zhang: j.zhang-8@student.utwente.nl

1. If you want to buy or sell your property, what method would you use to assess the price?

___

2. If a online estimation of property prices service is provided, would you use such service? (You can simply fill in the information of the property and get the predicted price.)

___

3. Do you think this type of online valuation is reliable? Will you use is as a reference?

___

4. These are the influential factors found during the MSc research. Please check the criteria you think is reflecting your opinion.

| Factor | Not important to me | Important to me | Unexpected | Not correct to me |
|---|---|---|---|---|
| Distance to high school (prices increase with distance increase) | | | | |
| Distance to metro station (prices decrease with distance increase) | | | | |
| Distance to tourist attractions (prices decrease with distance increase) | | | | |
| Distance to business centres (prices increase with distance increase) | | | | |
| Sun duration (prices | | | | |

| | | | | |
|---|---|---|---|---|
| increase with higher value) | | | | |
| View of buildings (%) (prices increase with higher value) | | | | |
| View of vegetation (%) (prices increase with higher value) | | | | |
| View of water (%) (prices increase with higher value) | | | | |

5. What are the factors that you think is important but were not contained in the table in question 4?

______________________________________________________________________

6. Do you think this valuation framework is applicable? Do you have any suggestions for improvement?

______________________________________________________________________